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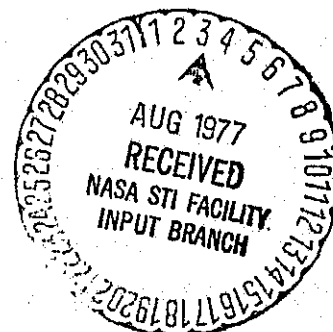
Orbital Construction Support Equipment

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MARTIN MARIETTA

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ORBITAL
CONSTRUCTION
SUPPORT
EQUIPMENT

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FOREWORD

This document was prepared by Martin Marietta Corporation under contract NAS9-15120, *Orbital Construction Support Equipment Study*, for the Johnson Space Center of the National Aeronautics and Space Administration and is submitted in accordance with Data Procurement Document Number SE-302T, Data Requirements List Number T 1094.

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1.0 INTRODUCTION

This report presents the results of the *Orbital Construction Support Equipment (OCSE)* study, Contract NAS9-15120, and describes the particular task activities conducted to achieve those results. The objectives of the study were to produce a conceptual design and system definition of the OCSE required for the construction in orbit of large space systems, typified by the Solar Power Satellite (SPS) proposed configurations, and to derive supporting development and cost data.

The Solar Power Satellite is several orders of magnitude larger than any prior system launched into orbit, or even fabricated and assembled on the ground. Thus, based on transportation costs, high density material will be launched and a significant amount of on-orbit fabrication and assembly will be provided by on-orbit construction equipment. This equipment will have to be assembled, positioned, set up, controlled, monitored, serviced, and maintained with specially-trained personnel located at the construction site. The special equipment required to perform these types of functions has been classified as Orbital Construction Support Equipment (OCSE). Present indications are that many diverse support equipments will be required and, although the specific equipment may be dependent on the nature of the large space structure system to be constructed, the basic principles of construction are such that much of the support equipment is common. This equipment commonality factor was stressed throughout the study effort.

Three SPS baseline configurations, shown in Figure 1.1, were selected by the NASA for application to this study. These concepts--the Photovoltaic Column/Cable SPS, the Photovoltaic Truss-type SPS, and the Thermal Engine SPS, represent the typical spectrum of present SPS configurations.

The SPS systems have been structured as illustrated in Figure 1-2. Analyses and/or design studies have been or are being conducted, both internally by the NASA and contractually by industry for each element of the system to varying degrees. As the figure indicates, this study addressed only the Orbital Construction Support Equipment portion of the system.

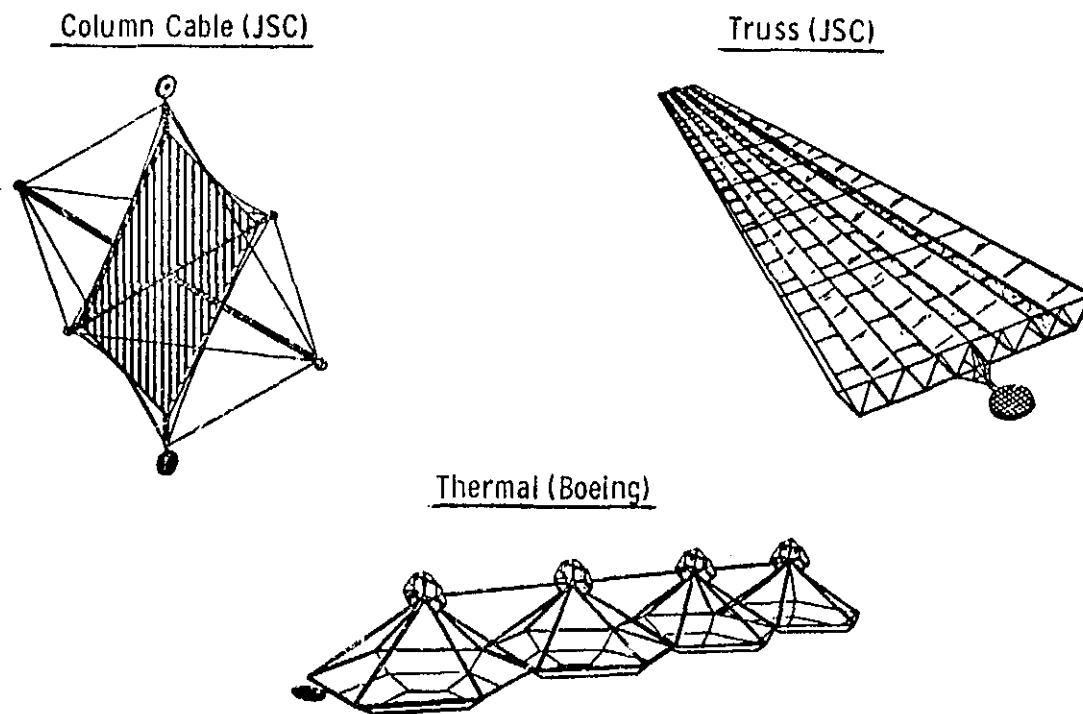


Figure 1-1 SPS Baseline Configurations

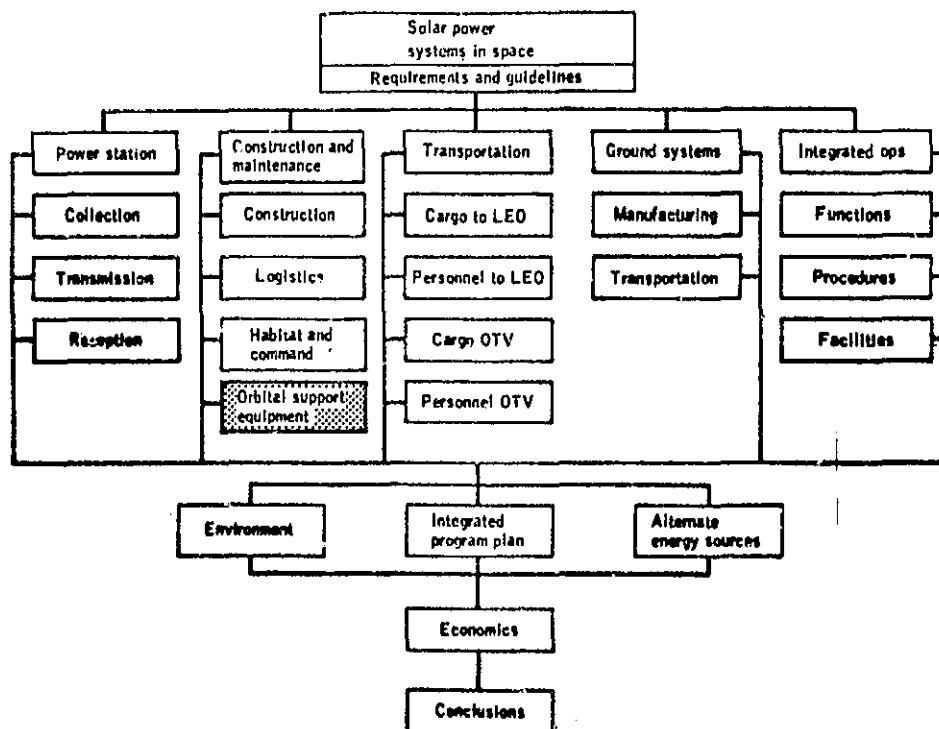


Figure 1-2 SPS Study Task Structure

The study consisted of three major parts as described in the following paragraphs. Figure 1-3 depicts the overall study flow and shows the inter-relationship of the individual parts.

1.1 Part I--Requirements Analysis

During Part I of the study, requirements were defined and categorized into system requirements which bound the study, support requirements for orbital construction of large space systems, and mission support equipment requirements for three SPS concepts--solar photovoltaic column/cable, solar photovoltaic truss and thermal engine SPS. These requirements were further defined by developing construction mission scenarios and associated functional activities analyses, and comparing the data with the on-orbit operations capability of man. The result of this activity aided in identifying the construction equipment necessary and in defining the support requirements of that equipment.

1.2 Part II--OCSE Concept Definition

Concept alternatives for the total range of support systems were developed which satisfied those requirements defined in Part I. An iterative approach was used to match the functional support activities derived in Part I with the OCSE candidates to assure all viable options were considered. Once equipment concepts were identified, integrated conceptual systems were derived which best combined the construction crewman, support equipment, and automated construction equipment. The emphasis on system integration was to build complete systems that illustrate OCSE concepts which offer various technical, operational, and programmatic advantages.

1.3 Part III--OCSE Concepts Evaluation/Selection

During the final part of the study, the concepts developed and screened in Part II were analyzed in sufficient detail to reduce the number of OCSE items to the most justifiable for further evaluation. The selected concepts were defined analytically and graphically in sufficient detail to provide for the preparation of estimated costs and development plans. An important portion of the plan was the identification of OCSE for an operational SPS

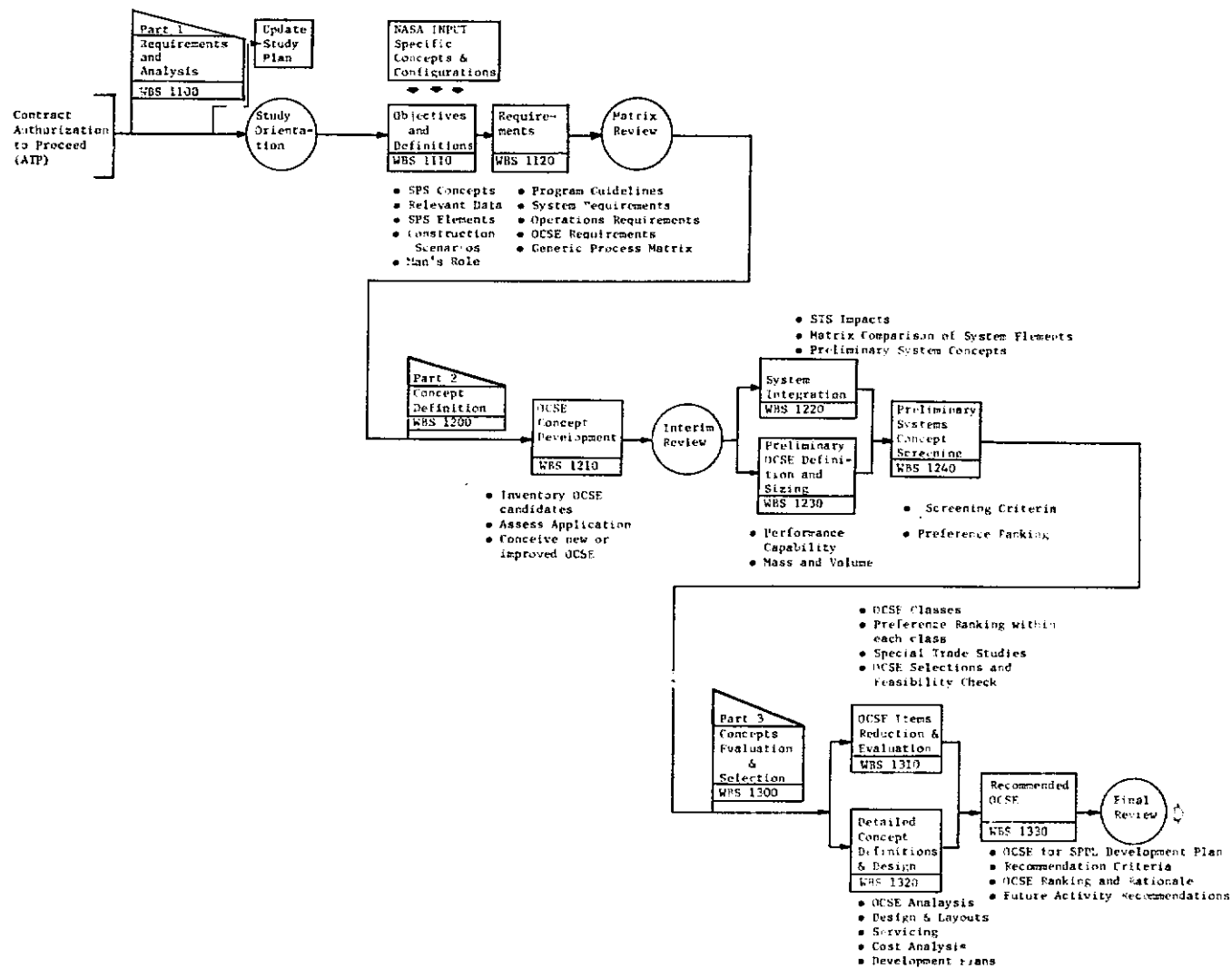


Figure 1-3 Study Work Flow and Subtask Relationships

and the relationship to the use of developmental OCSE in the build-up and testing of the SPS "Pilot Plant." The final output of this study was the selection and recommendation of a representative OCSE element for possible follow-on design, fabrication, and development testing.

1.4 Program Guidelines and Assumptions

The number and diversity of SPS definition studies currently being conducted within the NASA and by industry for the NASA, and the consequent continuing evolution of concepts and designs, make it mandatory that meaningful study guidelines be established and maintained. Program guidelines and assumptions provided by the NASA at the start of the study have been utilized throughout to define and bound the effort. As with any undertaking of the magnitude of the SPS program, the guidelines used can be very influential on the final results. Therefore, the ground rules must be clearly defined to provide a common understanding of study requirements.

The program guidelines and assumptions established for this study are as follows:

- a) Construction date of the first operational SPS will be 1995.
- b) SPS construction will be supported by a space construction base which provides for the needs of the construction crew, provides an operations center, provides logistics storage and control, and provides the facilities for any service required by the construction support equipment.
- c) Construction of a solar power development laboratory (SPDL), for this study referred to as a "pilot plant," will begin in low earth orbit in 1985 using the same construction techniques as planned for the operational SPS. The purpose of the pilot plant is to provide an R&D capability to assess all the critical elements that require evaluation or demonstration, including construction and associated support equipment operation. Potential differences between pilot plant (in LEO) and SPS (GEO) operations should be taken into consideration; that is, scale factor differences of 15 to 1 and day-night cycle perturbations should be identified.
- d) Pilot plant construction will be supported by a space construction base which provides services for the pilot plant in the same manner as that for the SPS.

e) The OCSE to be defined in this study is for support of the operational SPS. In order to accomplish the objectives of the earlier pilot plant, OCSE used in its construction should be as near like the eventual operational SPS equipment as possible.

f) Initial state of the art technology shall be that which is available in 1980. Design improvement for SPS construction support can consider 1990 technology.

g) OCSE used in the construction of the SPDL shall be compatible with the Shuttle Transportation System. SPS construction requires a new heavy lift launch vehicle (HLLV) and other orbital transfer vehicles.

h) Study effort will not be expended to originate designs for construction/fabrication equipment, but will utilize designs from companion studies in order to derive OCSE requirements.

1.5 Design Guidelines

In addition to the program guidelines defined for the study, several design guidelines were established to provide assistance in the formulation of OCSE concepts. The design guidelines supplied by the NASA to Martin Marietta are as follows:

a) Three SPS configurations chosen by JSC will be used for this study--solar photovoltaic column/cable concept, solar photovoltaic truss concept, and thermal engine concept.

b) The OCSE shall be designed for repeated use in the construction of a number of large space systems.

c) The entire construction system will operate in a zero-gravity environment.

d) Pressurized equipment (other than suits) shall be designed to accommodate a nominal 14.7 psi, earth-like atmosphere. Systems may be operated at lower internal pressures to reduce or eliminate prebreathing time if proved advantageous for extensive suited extravehicular operations.

e) Support vehicle crew size shall be a function of support requirements. Isolated EVA crewmen shall operate in pairs.

f) Concept design shall emphasize functional performance rather than such things as redundancy, environmental control and power supply which will be investigated only to the extent necessary to determine major impacts on the OCSE concepts.

2.0 SUMMARY AND CONCLUSIONS

2.1 Summary

The three major parts of this study are summarized in Figure 2.1-1. In Part I, approximately 200 separate construction steps were defined for the three SPS concepts. Detailed construction scenarios were developed which described the specific tasks to be accomplished and identified general equipment requirements. The scenarios were used to perform a functional analysis, which resulted in the definition of 100 distinct SPS elements. These elements are the components, parts, subsystems, or assemblies upon which construction activities take place. Table 2.1-1 shows the major SPS element for each configuration. For those elements, 300 functional requirements were identified in seven generic processes. Cumulatively, these processes encompass all functions required during SPS construction/assembly. Individually each process is defined such that it includes a specific type of activity. Each SPS element may involve activities relating to any or all of the generic processes. Figure 2.1-2 lists the processes and shows an example of the requirements defined for a typical element.

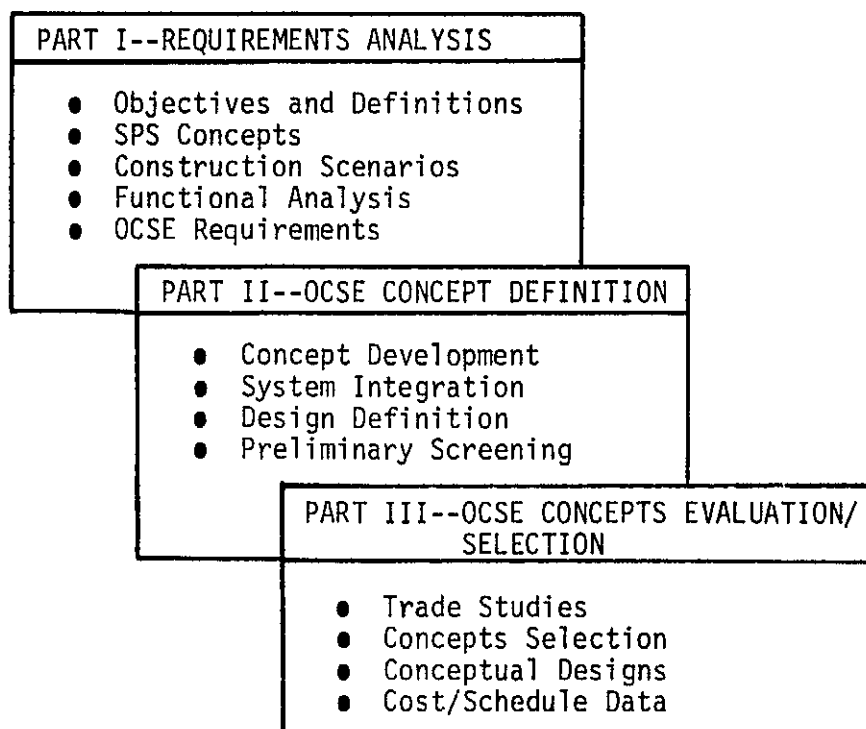


Figure 2.1-1 Study Overview

Table 2.1-1 Major SPS Elements

COLUMN/CABLE SPS	TRUSS TYPE SPS	THERMAL SPS
<u>STRUCTURAL SUPPORT</u> ● Main Columns ● Cable System - Main Cables - Prime Cables - Suspension Tapes - Peripheral Cables	<u>STRUCTURAL SUPPORT</u> ● Longitudinal Columns ● Transverse Beams ● Tension Cables	<u>POWER CONVERSION SYSTEM (PCS)</u> ● Cavity Absorbers ● Turbo Machines ● Power Distribution ● Radiators ● Fluid Piping
<u>SOLAR ENERGY COLLECTION SYSTEM (SECS)</u> ● Solar Cell Blankets ● Concentrator Blankets	<u>SOLAR ENERGY COLLECTION SYSTEM (SECS)</u> ● Solar Cell Blankets ● Concentrator Blankets	<u>SOLAR CONCENTRATOR (SC)</u> ● Support Struts ● Concentrator Framework Structure ● Support Structure ● Reflector Facets ● Facet Steering Control
<u>MICROWAVE POWER TRANSMISSION SYSTEMS (MPTS)</u> ● Column Extension Structure ● Ball Joint ● Support Structure ● Microwave Subarrays ● Operational Equipment - Phase Control - Power Distribution - Pointing Control - Counterweight System	<u>MICROWAVE POWER TRANSMISSION SYSTEMS (MPTS)</u> ● Extension Support Structure ● Rotary Joint ● Support Structure ● Microwave Subarrays ● Operational Equipment - Phase Control - Power Distribution - Pointing Control	<u>MICROWAVE POWER TRANSMISSION SYSTEMS (MPTS)</u> ● Rotary Transformer Assembly ● Support Structure ● Microwave Subarrays ● Operational Equipment - Phase Control - Power Distribution - Pointing Control
<u>AUXILIARY EQUIPMENT</u> ● Attitude Control ● Instrumentation & Communications ● Counterweights	<u>AUXILIARY EQUIPMENT</u> ● Attitude Control ● Instrumentation & Communications	<u>AUXILIARY EQUIPMENT</u> ● Attitude Control ● Instrumentation & Communications

SPS Element	Mass (Unit/Total)	Element Characteristics		Generic Processes						
		Configuration	Process Cycles	Transport		Handle		Fasten	Monitor	Checkout
				Distance	Attachment Considerations	Distance	Constraints/Support Reqmts.	Task Description	Parameter	Parameter
Electrical Conductors (Between Joint & SECS)	63 kg/m CC: 47,250 kg/Conductor TT: 31,500 kg/Conductor BT: TBD, Small Dia	C/C: 17 cm dia. 750 m long each TT: 12 cm dia. 1km long each BT: 3 lines, 5 m long each (AC - Small dia)	C/C: 4 Lines Per MPTS TT: 8 Lines BT: 3 Lines Per MPTS	C/C: 1F To MPTS - 13 mi FF 18 mi Attached TT: CF To Joint - 1km BT: CF To Joint - 50m	Transportable On Reels; Cable Avoidance (C/C)	Joint To SECS - C/C 750 m TT - 1 km	Transported Between Attach Points, If Not Handled Accuracy: 2 cm	Quick Disconnect Concept; May Require External Force/Torque Mechanism And Fine Dexterity (EVA)	Conductor Cable Attachment Direct Or Remote Visual Contact	Electrical Continuity (Between Joint & Distribution Points) - Up To 1 km long
NOTE: Align, adjust processes not required for this element.										

GENERIC PROCESSES:

Transport	Adjust
Handle	Monitor
Align	Checkout
Fasten	

Figure 2.1-2 Typical SPS Element with Corresponding Generic Process Requirements

As a result of the Part I analyses, the construction equipment required by each SPS concept was defined and the support requirements for that equipment were established. Figure 2.1-3 depicts the method whereby construction functions (in terms of the generic processes) were utilized to generate OCSE, and how these OCSE items were classified into broad groups. Based on the usage classifications shown, 11 groups of potential OCSE were identified. These groups are listed in Table 2.1-2.

Concept definitions for the OCSE were established in Part II of the study. In addition, over 100 candidate OCSE concepts in the 11 groups were identified. A process was developed by which the concepts could be screened across 12 criteria so that a list of OCSE for which conceptual designs would be established in Part III was defined. Figure 2.1-4 shows a portion of the comparison matrix, identifies the screening parameters, and lists the 11 selected items of OCSE.

The OCSE system descriptions developed during Part III of the study for each of the 11 items contained the information listed in Table 2.1-3.

Table 2.1-3 OCSE System Descriptions

● Operational Description	
● Crew Participation	● Interface Considerations
● Concepts	● Cost Data (under separate cover, Appendix B)
● Subsystems	● Development Plan
● Environmental Factors	

Applications of OCSE to SPS Pilot Plants (1985) were also investigated in Part III. An OCSE development priority was established, as shown in Table 2.1-4, based upon Pilot Plant considerations. This shows that the items requiring the earliest flight-operational units (1984) are the manipulator (fixed or mobile), the manned cherry picker (boom or structure attached) and the basic fabrication/assembly concept of the Central Hub Assembly/Deployment module. The other items require the first operational units between 1985 and 1989. Finally, an overall schedule was defined to show the required technology studies and the OCSE development schedules in relation to each other. This is depicted in Figure 2.1-5.

SPS ELEMENTS	CONSTRUCTION FUNCTION	POTENTIAL CONSTRUCTION EQUIPMENT	SUPPORT REQUIREMENTS
I. TRIANGULAR BEAMS - SECS Support Trusses (1200) - MPTS Extension Structure	- HANDLE beams to assemble structure - ALIGN beams as sections are assembled. - FASTEN beams together - probe and drogue requiring external torque (multiple joints @ one operation) - ADJUST beam end fittings to align diagonal beam plane	Beam and Beam Assembly Transporter - Receive beams - Beam holddowns - Beam release Beam Handler - Beam translation - Position for alignment - Adjust after fastened Beam Fastener - Fasten beams - Adjust beams	Mobile Beam Transporter (on Structure) - Assemble on orbit or launch from ground - Transport to structure - Placement on rails or cables - Communications link - Electrical power recharge - Operational checkout - Maintenance and repair Fixed Base Manipulators - Assemble on-orbit or launch from ground - Transport to construction site - Alignment for mounting - Fasten to construction facility - Service and repair Small Highly Dexterous Manipulator - Launched from ground - Transport to construction site



SPS Element Group No.	SUPPORT REQUIREMENTS	POTENTIAL OCSE	MAJOR DESIGN DRIVERS	OCSE COMMON USAGE CLASSIFICATION
I. TRIANGULAR BEAMS	Mobile Beam Transporter (on Structure) - Assemble on-orbit or launch from ground - Transport to structure - Placement on rails or cables - Communications link - Electrical power recharge - Operational checkout - Maintenance and repair Fixed Base Manipulators - Assemble on-orbit or launch from ground - Transport to construction site - Alignment for mounting - Fasten to construction facility - Service and repair Small Highly Dexterous Manipulator - Launched from ground - Transport to construction site - Interface with fixed base	Launch from ground Transporter, free-flying Facility manipulator/TV and lights Antenna module Small 3 DOF manipulator TV and lights or instruments Railed EVA work platform Launch from ground Transporter, free-flyer Facility manipulator/TV and lights Small manipulator/EVA Small manipulator/EVA Receive from launch vehicle Transporter, free-flyer	Designed to fit within HLLV Man-in-the-loop control Man-remote control Replaceable module, function of distance Battery storage or recharge stops Motion, current, force Replaceable modules Erectable structure Size Prepared surface on jig EOTS size, cherry picker EOTS size, cherry picker Small free-flyer, EOTS size	Universal docking device FF Trnsptr Antenna mod., 10 Km range Battery Recharge Station TV & Lighting System Common Replacement Modules Free-Flying Transporter One man cherry picker One man cherry picker FF Trnsptr

Figure 2.1-3 Generation of OCSE from Construction Functions for SPS Elements

Table 2.1-2 List of Potential OCSE

- Free-Flying Transporters
 - Personnel and Materials
 - Materials Transporter
 - Personnel Transporter
- Structure Attached Transporters
 - Personnel and Materials
 - Materials Transporters
 - Personnel Transporter
- Handlers
 - Manipulators 5 DOF (Arm-like)
 - General Purpose 4 DOF Mechanisms
- Aligners
 - Align for Joining
 - Flatness
 - Depth and Range
- Material Fasteners
 - Manipulator Controlled
 - EVA Controlled
 - Inherent with Structure
- Adjustment Devices
 - Beam Positioners
 - Inherent with Structure
 - Cable Tensioners
- Checkout
 - Input Simulators
 - Data Feedback Sensors
- Monitor Devices
 - Indirect Viewing
 - Direct Viewing
 - Instruments
- OCSE Support Equipment
 - Docking Devices
 - Commodity Servicer
 - Storage Panels
 - Modularized Systems
- Integrated Systems
 - Structure Attached Mobile Manned Vehicle with Attached Manipulators
 - Free-Flying Manned Vehicle with Attached Manipulators
 - Remote Manned Teleoperator Vehicle Structure Attached
 - Remote Manned Teleoperator Vehicle Free-Flying
- Base Modules
 - Central Hub Assembly/Deployment Module
 - Maintenance and Repair Module
 - Commodities Storage Module
 - Assembly Jigs
 - EVA Module

● Comparison Matrix

OCSE CONCEPTS	SCREENING PARAMETERS												
	TASK CYCLES	PERFORMANCE FLEXIBILITY	PERFORMANCE REDUNDANCY	SIZE	DEVELOPMENT IMPACTS	CONCEPT DESIGN ANOMALIES	INTERFACES	STATE OF THE ART	SRT TIME PHASING	POTENTIAL OBSOLESCENCE	ADAPTABILITY TO GROUND VERIFICATION	REPRESENTS SPS BASELINES	NUMERICAL RANKING AND SCORE
● Base Modules													
- CHAD Module	H	H	H	H	H	M	H	M	H	M	M	H	2/20
- EVA Module	H	H	M	M	M	M	H	M	H	M	M	H	5/17
- Commodities Storage Module	H	L	M	M	M	H	H	H	H	H	M	H	4/18
- Maintenance and Repair Module	M	H	M	M	H	H	H	M	M	M	H	H	4/18
- Assembly Jigs	L	L	H	H	H	M	M	H	H	M	M	L	8/14
● Transporters													
- Personnel Transpr Free Flying Suited, Open Structure	L	H	M	M	M	L	H	L	M	H	M	H	9/13
	L	H	M	M	M	L	H	L	M	H	M	H	9/13
	L	H	M	M	M	L	M	L	M	H	M	H	11/11
	L	H	M	M	M	L	M	L	M	H	M	H	8/14

fixed or mobile base, or dual, ≥ 5 DOF

ice for joining large systems

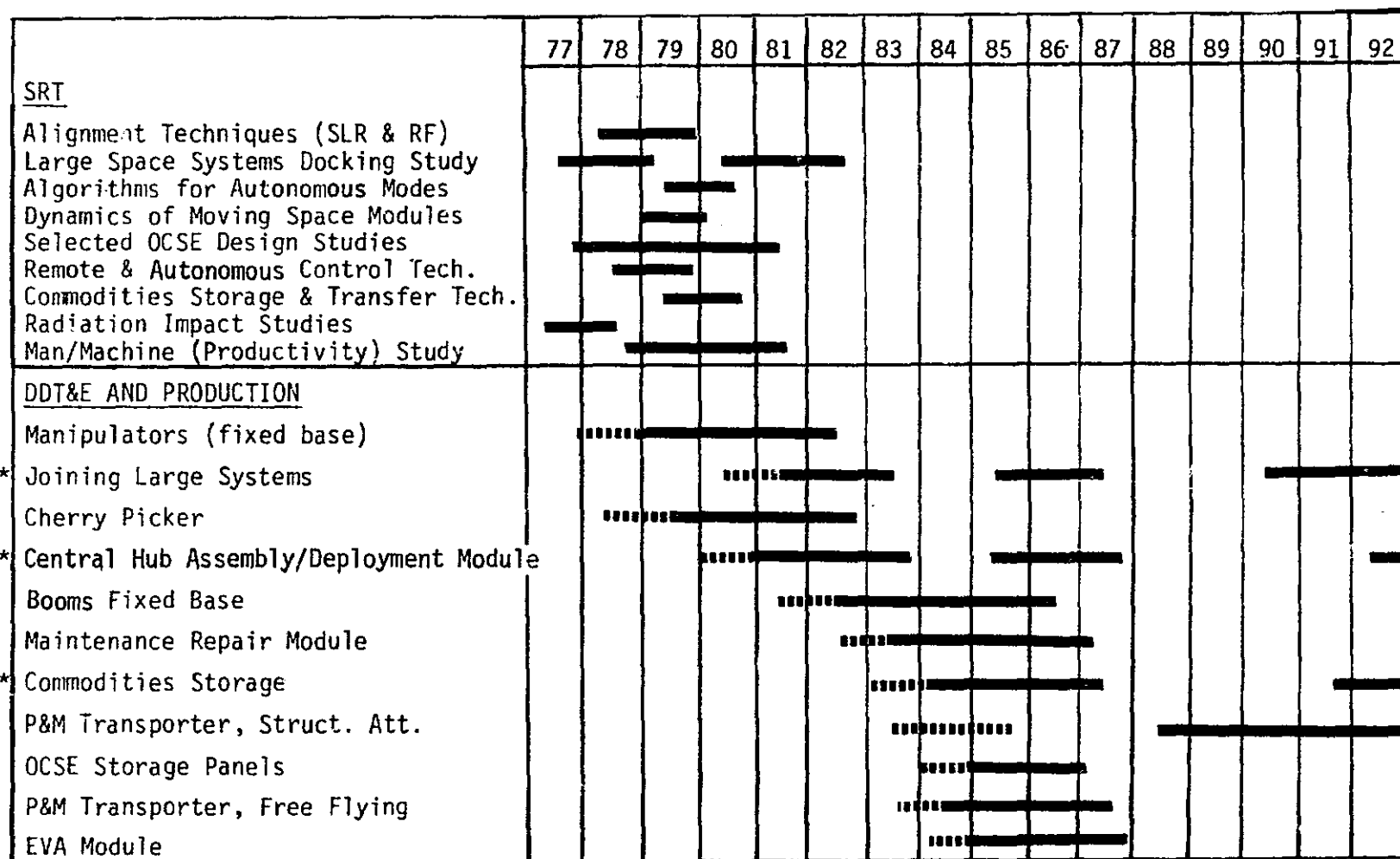
● Selected OCSE

- Manipulator, fixed or mobile base, or dual, ≥ 5 DOF
- Docking Device for joining large systems
- Manned Cherry Picker, attached to boom or structure
- Central Hub Assembly/Deployment (CHAD) Module
- Fixed-base Boom, long/extendable, ≤ 4 DOF
- Maintenance Repair Module
- Commodities Storage Module
- Personnel/Material Transporter, structure attached
- OCSE Storage Panels
- Personnel/Material Transporter, free-flying
- EVA module

Figure 2.1-4 Screening Analysis Matrix and Selected OCSE

Table 2.1-4 OCSE Development Priority

OCSE	1984	1985	1986	1987	1988	1989 & BEYOND
Manipulator (Fixed or Mobile Base)	X					
Docking Device (for Large Systems)		X				X
Manned Cherry Picker (Boom or Structure Attached)	X					
Central Hub Assembly/Deployment Module (Basic Fab/ Assy Concept)	X					
Fixed-base Long Boom						X
Maintenance Repair Module				X		
Commodities Storage Module			X			
Personnel/Material Transporter (Structure Attached)						X
OCSE Storage Panels		X		X		X
Personnel/Material Transporter (Free-flying)		X				
EVA Module		X		X		X



* 1985 Different Configuration
than 1995

Design Phase

Figure 2.1-5 Selected OCSE Schedule Summary

2.2 Significant Results and Recommendations

2.2.1 Significant Results

The complete results of this study are reported in subsequent sections of this report. However, some of the more significant observations have been collected and summarized as follows:

a. Large Space Structure Commonality - Three different SPS configurations were analyzed during this study. Interestingly enough, while the basic configurations differed widely, the principles of construction were found to be similar. As a result, a large percentage of the OCSE was common irrespective of the particular SPS configuration. The dependency of the OCSE on configurations were in areas such as size, length, and number required as opposed to functional type requirements.

b. Man's Involvement - Man's involvement in the construction process needs further definition. The basic work shift philosophy, the level of EVA, and man's productivity should be established.

c. Timeline Considerations - The rate of SPS construction needs additional definition. This impacts the OCSE in that it affects the number of pieces of OCSE required, provides rationale for mobile vs fixed type OCSE based on usage frequency, and establishes the rates (or speeds) required of the OCSE.

d. Operational Maintenance - Upon completion of an SPS, the OCSE moves to the next work site for subsequent SPS construction. In many instances, the OCSE element is aptly suited for operational maintenance. This role for OCSE should be addressed in the future.

e. Simulation Techniques - New simulation techniques for large scale operations will be required. The dominant factors to be considered are the one "g" environment and the scaling of the structure. In some cases a portion of the large structure may be constructed full scale while in others, a sub-scale model of the complete structure will be used.

f. OCSE Tradeoff Studies - One of the results of some of the preliminary OCSE tradeoff studies was the lack of sufficient support rationale to make a

clear selection of one over another. For example, both long booms and manipulators were found to play a role in orbital construction. The long boom primarily provides a transport path or material supply function while the manipulator performs the handling and installation activity. From another point of view, when the length requirement on a manipulator becomes excessively long, booms become more attractive.

g. Orbital Construction Equipment - The interrelationships between the orbital construction equipment and the OCSE is apparent. Therefore, complementary studies defining automated orbital construction equipment should be initiated.

h. Construction Jigs - Additional emphasis should be placed on the use of construction jigs and fixtures in the construction of large space systems. The jigs and fixtures are about the same size as the SPS structure but in general will be stiffer, built to closer tolerances, and incorporate alignment references. As these jigs will provide the basic support platform for some of the OCSE elements, the OCSE requirements (e.g., manipulative length) are dependent on the relative location of the jig with respect to the work site installation areas. Therefore, the application of jigs, and their interrelationship with and effects on the OCSE, should be investigated including fixed, mobile, and relocateable types.

2.2.2 Recommendations - Based on the evaluations and discussions presented in this study and the initial study objective to select and define the preferred piece of OCSE for potential follow-on design, fabrication, and development testing, it was determined that the manned cherry picker, and related supporting research and technology, was the top selection.

a. Supporting Research and Technology - Critical technology areas were identified for each of the OCSE and included such items as alignment techniques, material fastening techniques, vehicle attached translation on structural interfaces, dynamics and control associated with movement of large masses in space, berthing of large space systems, and contamination sensitivity during construction and assembly. In numerous cases, a similar or identical technology problem was mentioned in connection with more than one OCSE as indicated in Table 2.2.2-1. These overlapping OCSE technology areas should

Table 2.2.2-1 Overlapping Technology Areas for OCSE

OCSE	OVERLAPPING TECHNOLOGY AREAS													
	Manipulators	Alignment	Docking	Thermal Control	Vehicle/Track Interfaces	Life Support Provisions	Handling and Positioning Required	Stabilization and Control	Communication	Handling and Berthing of Unit	Remote Manned Control	Autonomous Control	Hybrid Control System	Mechanical Connectors
• Manipulator, fixed or mobile base, or dual, ≥ 5 DOF	X	X		X	X		X		X	X	X	X	X	X
• Docking device for joining large systems	X	X	X	X			X		X	X	X	X	X	X
• Manned Cherry Picker, attached to boom or structure	X	X	X	X	X	X	X		X	X				X
• CHAD Module	X	X		X		X		X	X				X	X
• Fixed-base Boom, long/extendable, ≤ 4 DOF	X	X		X					X	X	X	X	X	X
• Maintenance Repair Module	X	X	X	X		X	X		X	X	X			X
• Commodities Storage Module	X	X	X	X				X	X		X	X	X	X
• Personnel/Material Transporter, structure attached	X	X		X	X	X	X		X	X				X
• OCSE Storage Panels	X	X	X				X		X	X	X	X		X
• Personnel/Material Transporter, free-flying	X	X	X	X	X	X	X	X	X	X				X
• EVA Module		X	X	X		X	X		X	X				X

be investigated in a single study covering the spectrum of OCSE requiring that technology. For example, a study on alignment techniques for large space structure construction applications may be preferable over separate studies in which each element of OCSE addresses alignment.

b. OCSE Follow-on Recommendation - As a result of this study an OCSE development preference ranking was generated. The four top items in order of preference were the manned cherry picker, docking of large systems, manipulator (50 m), and the central hub assembly/deployment module. The top item recommended was a cherry picker, because this element of OCSE is required during the early phases of SPS activity and is highly involved in pilot plant construction. Development of this item should be consistent with other aerospace hardware development programs. However, it is recommended that early hardware development make use of the NASA protoflight concept. This concept uses early flight testing of subsystems to reduce the number of test hardware units, reduce the extent of ground testing and utilizes the Shuttle to return hardware for post-test inspections and analyses. This fits into the basic programmatic philosophy of keeping cost down.

A key term associated with low cost programs and involved in many different phases of this study was commonality. Commonality of design, commonality of hardware, commonality of test facilities, commonality of technology, etc all played a major role in determining the development preference. For example, the pressurized cab used on the cherry picker to house the operator, is very likely the same hardware that can be used on the other manned transport vehicles needed downstream. The basic development plan proposed for the cherry picker is typical for each of the OCSE items, with the exception of time phasing and some of the unique subsystems requirements. The plan as laid out has five primary phases to complete development/demonstration: 1) design study; 2) proof of concept (engineering model); 3) protoflight unit; 4) system integration; and 5) space demonstrations. These phases are discussed in detail in section 5.4.3.

2.2.3 Conclusions - The past eight months work have resulted in the generation of the first overall picture of the different parts OCSE plays

in orbital construction of the SPS. A number of different options were considered with data to support entry into follow-on work activities which should aid in reducing the uncertainties associated in committing to the development of an operational SPS. In addition the data base developed during this effort is presented in a format permitting NASA various options in preparing for future projects.

3.0 REQUIREMENTS ANALYSIS

3.1 Part I Objectives

During Part I of the study, SPS concepts definition was achieved and the corresponding OCSE requirements were defined. The concepts definition was achieved by collecting and organizing data relevant to the selected SPS configurations, establishing a detailed construction scenario for each concept and preparing functional activities analyses of each construction sequence. In addition, a spectrum of elements was defined for large space structures and the extent of man's role in the construction process was determined.

OCSE requirements were defined by establishing a finite set of generic processes which applied to the SPS elements, describing the construction functions required to complete each process, identifying the potential construction equipment which could accomplish those functions, and defining the support requirements of the construction equipment.

Figure 3.1-1 shows the functional flow of the Part I tasks and references the paragraphs in the remainder of this section where each step is described.

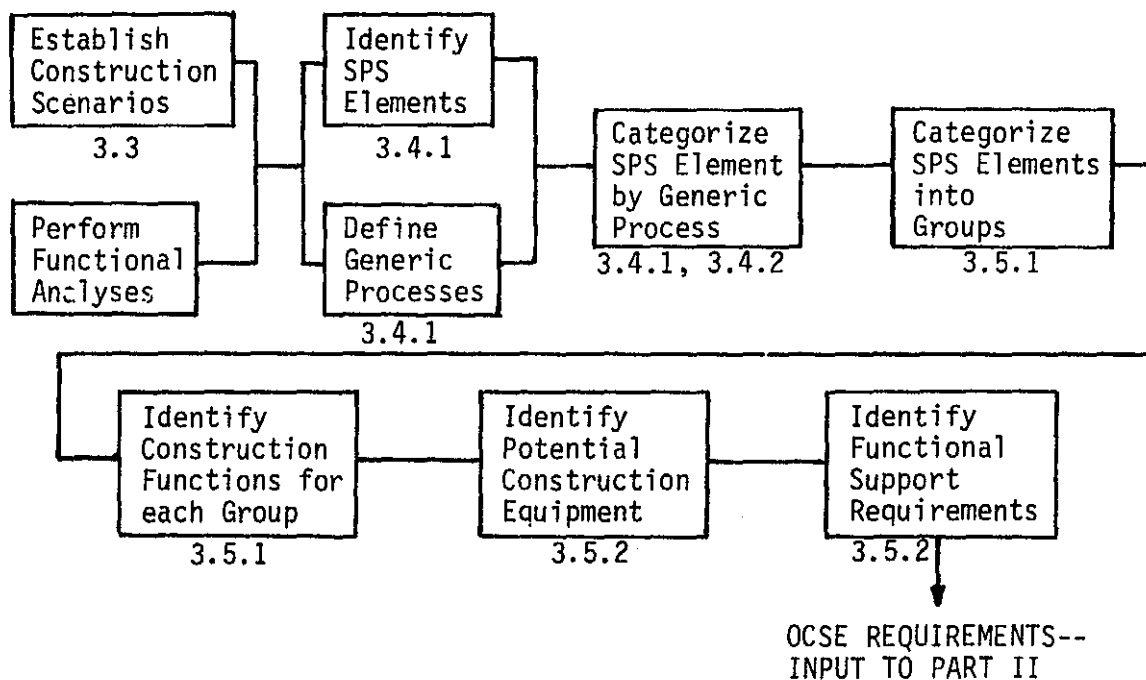


Figure 3.1-1 Functional Flow to Define OCSE Requirements

3.2 SPS Concept Baselines

Three solar power satellite (SPS) concepts were selected by NASA to be used as baselines for this study. These include two JSC concepts of solar photovoltaic systems⁽¹⁾: the column/cable type and the truss type. The third system is the Boeing Brayton-cycle thermal engine satellite. A thermionic emission power generation system was also considered but was later eliminated from consideration since the thermal engine system contained similar, as well as more diverse, construction tasks.

Scenarios were developed for constructing each baseline SPS to aid in visualizing required construction steps preparatory to defining specific functional activities. The scenarios were reiterated as necessary during the process of formulating feasible construction methods. The MPTS scenario is discussed separately (Section 3.3.4) because of commonality to all SPS systems.

3.2.1 Column/Cable (C/C) SPS Baseline

The general scenario for constructing the C/C SPS is presented in Figure 3.2.1-1. Eight construction facilities (CF) are assembled in LEO and boosted to GEO for subsequent SPS construction. A manufacturing facility (MF-1) will be maintained in LEO for assembling SPS elements too large for direct launch from earth; e.g., MPTS subarrays, solar cell rolls, secondary structures, etc. In GEO, CF-1 will build a hub for subsequent attachment of CF-2 thru CF-6. MPTS extension structures will be partially built outboard of CF-5 and CF-6. The MF-1's construction facilities (CF-7 and CF-8) will dock on this structure.

The construction proceeds with CF-1 thru CF-6 extending the columns, CF-2 and CF-3 installing the solar energy collection system (SECS) and deploying the peripheral cables, CF-5 and CF-6 installing $\pm X$ tape reels, and CF-1 and CF-3 deploying main and prime cables. Supplies from earth are brought to logistics facilities (LF) at CF-1 and CF-3 and are distributed by local transfer means to the other facilities as required.

Upon completion of construction, installation of auxiliary equipment, and systems checkout/activation the facilities not needed will be removed and maneuvered to a different construction site.

(1) Reference: *Initial Technical, Environmental and Economic Evaluation of Space Solar Power Concepts*, JSC 11568, NASA-JSC, August 1976.

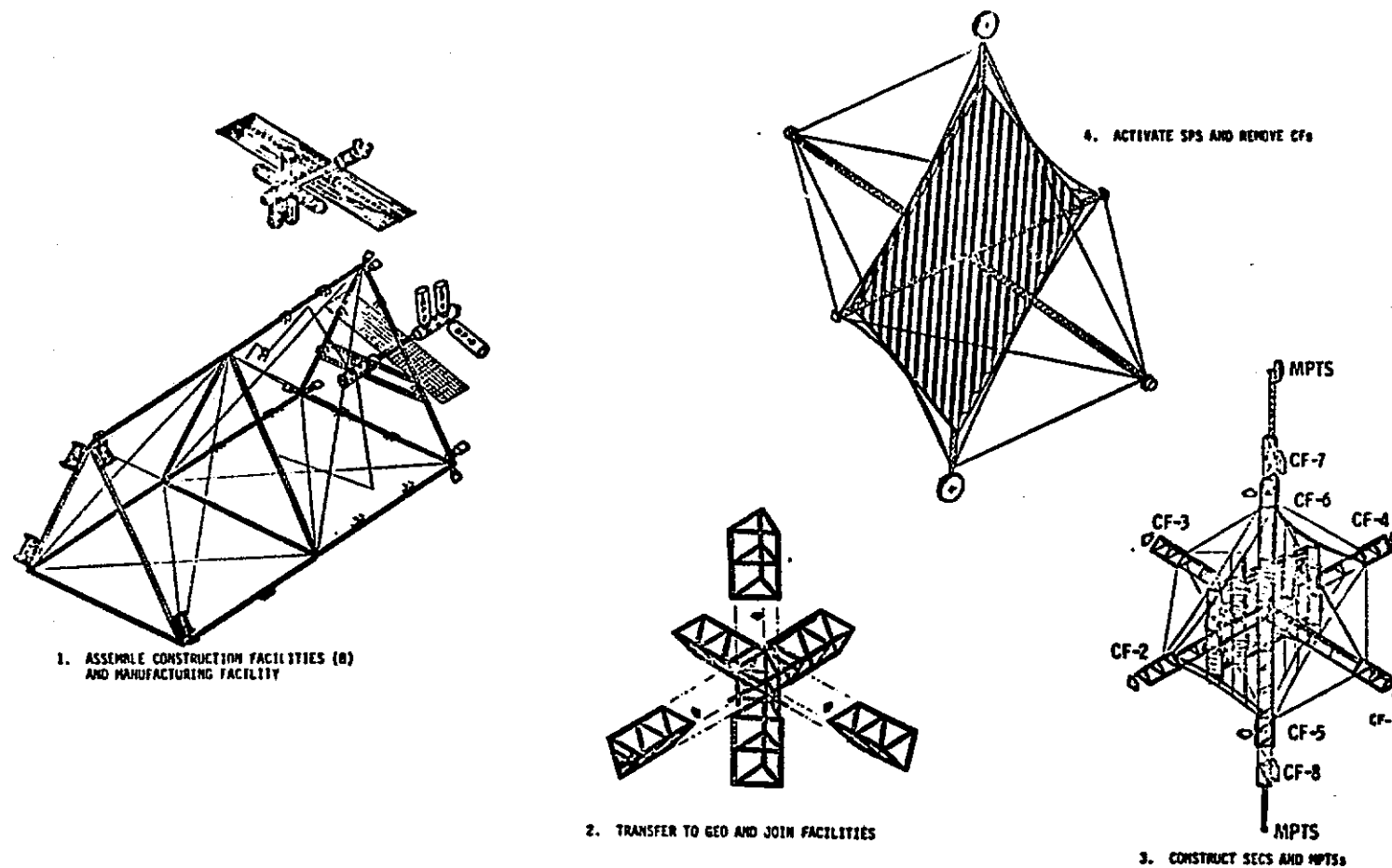


Figure 3.2.1-1 Column/Cable SPS - Construction Scenario

3.2.2 Truss Configuration (T) SPS Baseline

The general scenario for constructing the truss SPS is presented in Figure 3.2.2-1. One large construction facility (CF) will be assembled in LEO and boosted to GEO for subsequent SPS construction. A manufacturing facility (MF) will be maintained in LEO for assembling SPS elements too large for direct launch from earth.

In GEO, the main facility will build the SECS while additional facilities at the SECS end wall and facility will build the MPTSs. Auxiliary SPS equipment is installed as construction proceeds. When the SPS construction is completed, the MPTS extension structure at the facility end is spliced to the SECS end wall. When systems are checked out and verified, the SPS is oriented to the sun and the MPTSs are pointed to the earth and activated. The construction facility is then separated and maneuvered to another construction site.

3.2.3 Boeing Thermal Engine (BT) SPS Baseline

The general scenario for constructing the BT SPS is presented in Figure 3.2.3-1. Initially four construction facilities (CF-1 thru CF-4) will be assembled in LEO. These will independently assemble the four power conversion systems (PCS). Six beam builder facilities for each module (CF-5 thru CF-28) will be attached to structure at the bases of the PCSs. These facilities will construct the solar concentrator structure and install reflector facets while the PCS elements are installed. Simultaneously, a separate facility (CF-29) will construct the MPTS. A manufacturing facility (MF) will also be maintained to assemble SPS elements into larger elements to minimize construction tasks at the SPS modules (e.g., buildup of turbogenerator modules to minimize potential leak points to check when installed).

After all modules are completed, the MPTS is attached to the bottom of one module, propulsion units are attached, and the modules are separately boosted to GEO. In GEO, the modules and MPTS are joined, the spinal truss (power conductor) is assembled, and the SPS is checked out and activated.

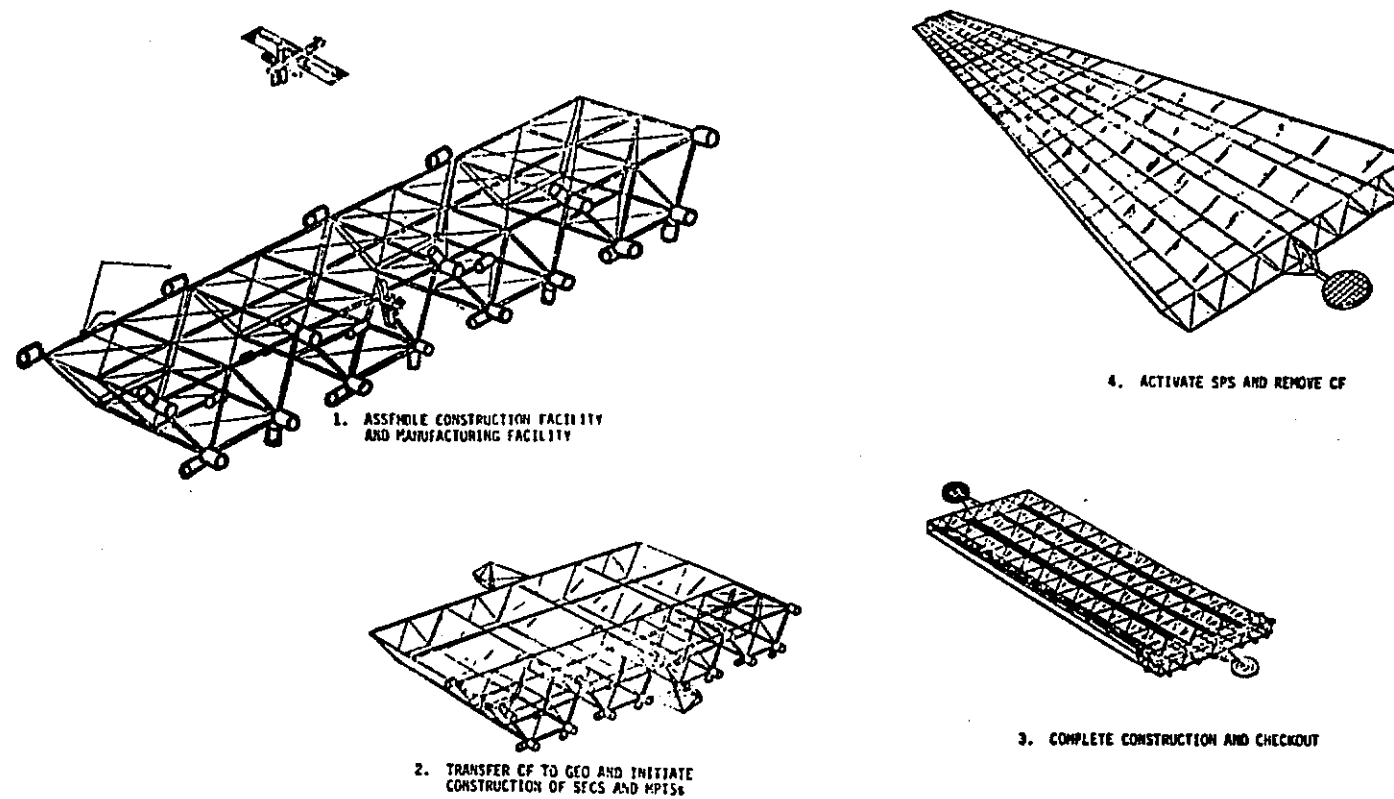


Figure 3.2.2-1 Truss Type SPS - Construction Scenario

PODLIFT FRAME

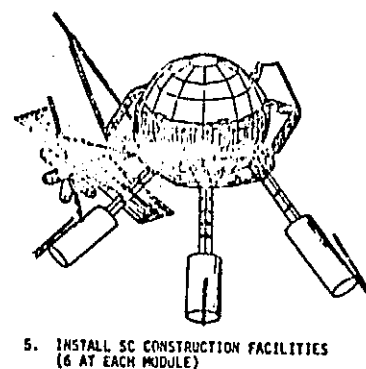
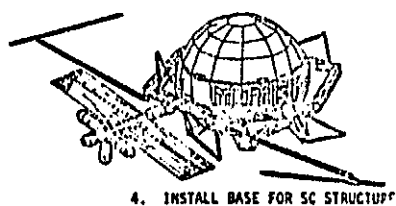
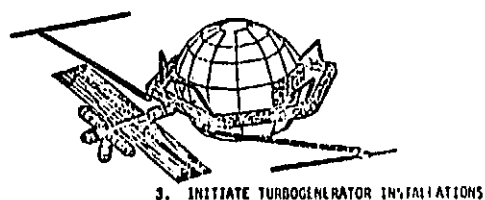
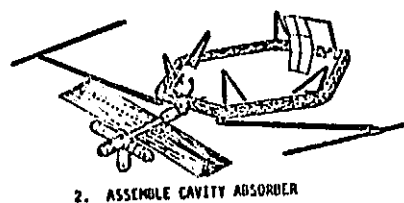
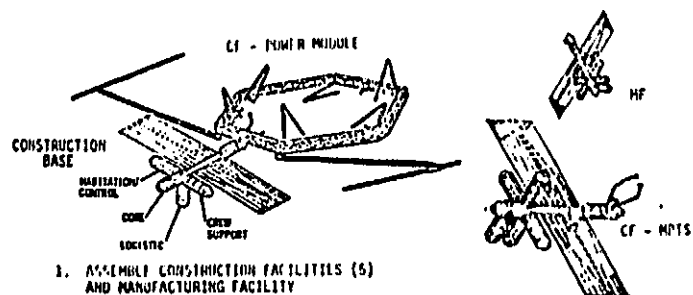
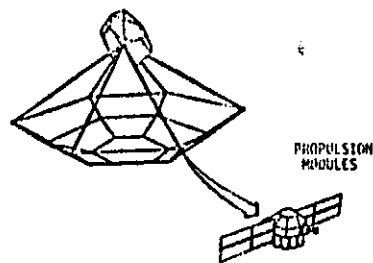
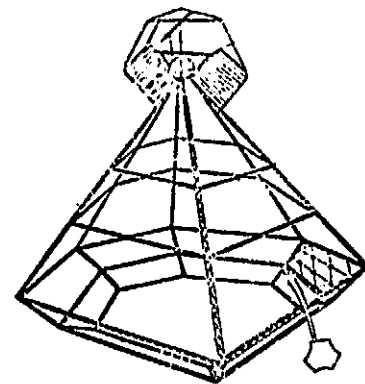


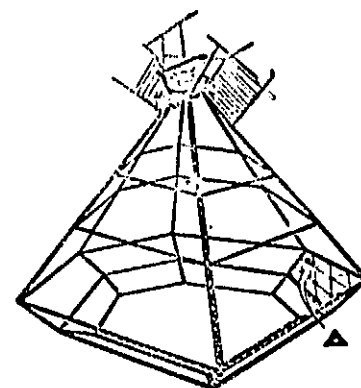
Figure 3.2.3-1 Thermal Engine SPS - Construction Scenario



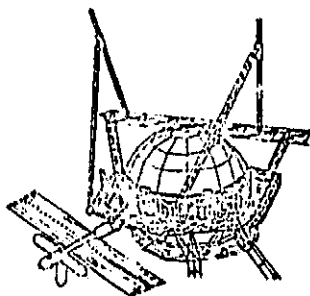
10. TRANSFER MODULES TO GEO



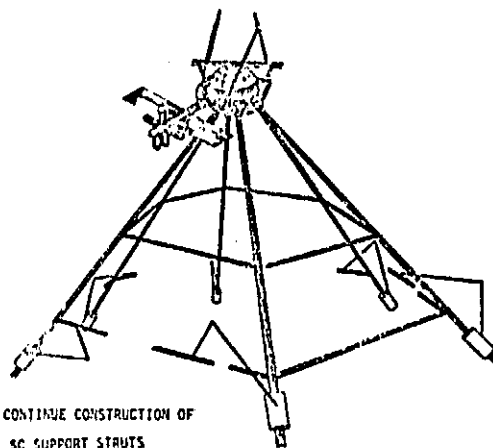
9. INSTALL REFLECTOR FACETS AND COMPLETE RADIATOR



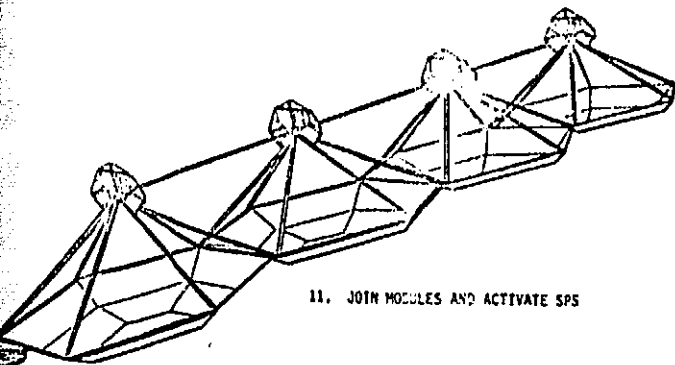
8. CONSTRUCT SUPPORT STRUCTURE FRAMEWORK AND INSTALL "POP-OUT" SECONDARY STRUCTURE



6. CONTINUE PCS CONSTRUCTION



7. CONTINUE CONSTRUCTION OF SC SUPPORT STRUTS



11. JOIN MODULES AND ACTIVATE SPS

REPRODUCIBILITY OF THE
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3.3 Construction Scenarios

Detailed construction activities and assembly requirements for the baseline SPS concepts are presented in this section. These scenarios are based on data provided by JSC (for the Column/Cable and Truss SPS) and the Boeing Company (for the Thermal Engine SPS). Additional construction details were generated by preparing functional analyses and construction schedules based on JSC timeline estimates.

Although proposed construction techniques will continue to evolve as the SPS definition studies proceed, it should be noted that the scenarios as presented here still provide a realistic description of the types of tasks which will be required for eventual SPS construction, whatever its ultimate configuration.

3.3.1 Solar Photovoltaic Column/Cable SPS

3.3.1.1 Overview - A view of the JSC column/cable (C/C) SPS is presented in Figure 3.3.1-1. The system contains much less supporting structure than exists in other concepts. The main structure consists of three truss-type cross columns with tension cables connected at each 3600-meter column increment to hold the columns in compression. The solar energy collection system (SECS) is a series of solar cell panels and concentrator sheets. The SECS is installed on the +X column and is deployed in the +Y directions (Figure 3.3.1-2). The SECS is held in a flat plane by a cross-pattern of secondary tapes on the top and bottom sides, and by prime cables that converge at the +Z column ends (Figures 3.3.1-3 and 3.3.1-4). The SECS is attached to the peripheral cables by the secondary tapes. The peripheral cables also serve to collect and transmit the electrical power from the SECS. The electrical energy generated in the solar cells is transmitted to the aluminized concentrator material and is conducted through the concentrator to the peripheral cables. The electrical power is further transmitted by large distribution cables to the microwave power transmission systems (MPTS) located at the ends of the +Y column.

3.3.1.2 Construction Activities - The baseline construction method assumed for the C/C SPS is to start at the center and work outwards. All applicable elements are installed and additional beam segments are assembled in increments. The columns are assembled by use of six construction facilities and supporting equipment, such as the concepts depicted in Figure 3.3.1-5.

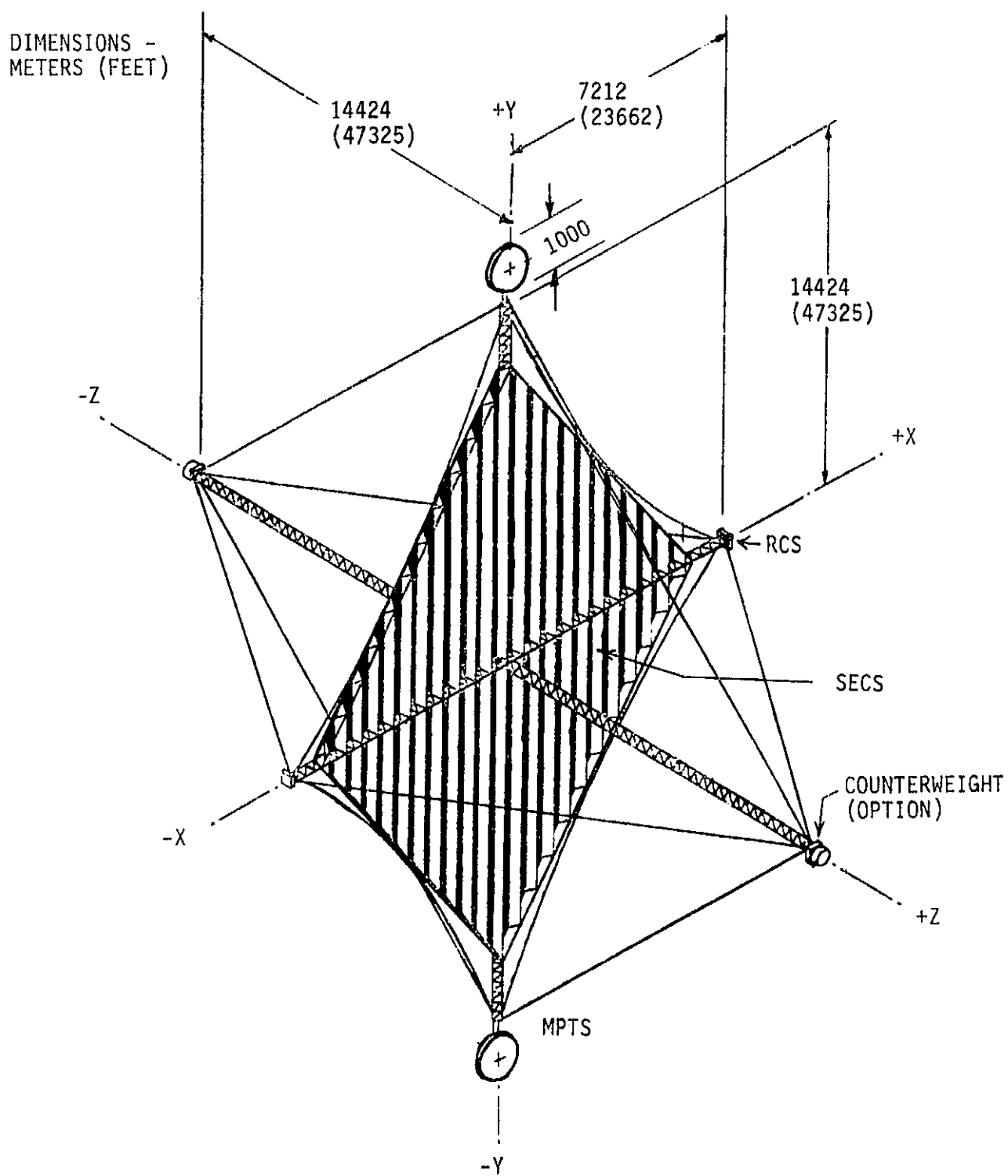


Figure 3.3.1-1 Column/Cable SPS

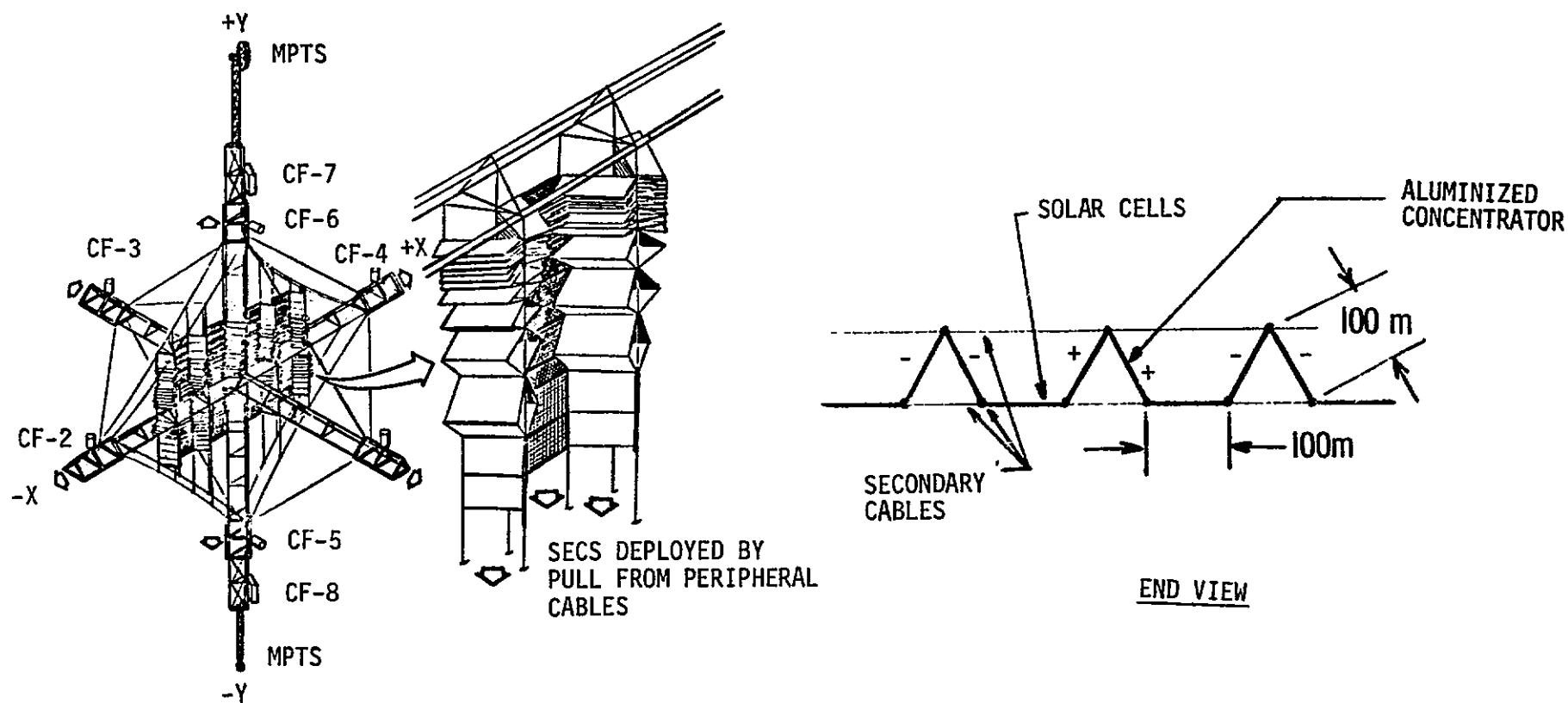


Figure 3.3.1-2 Column/Cable SPS - Solar Energy Collection System

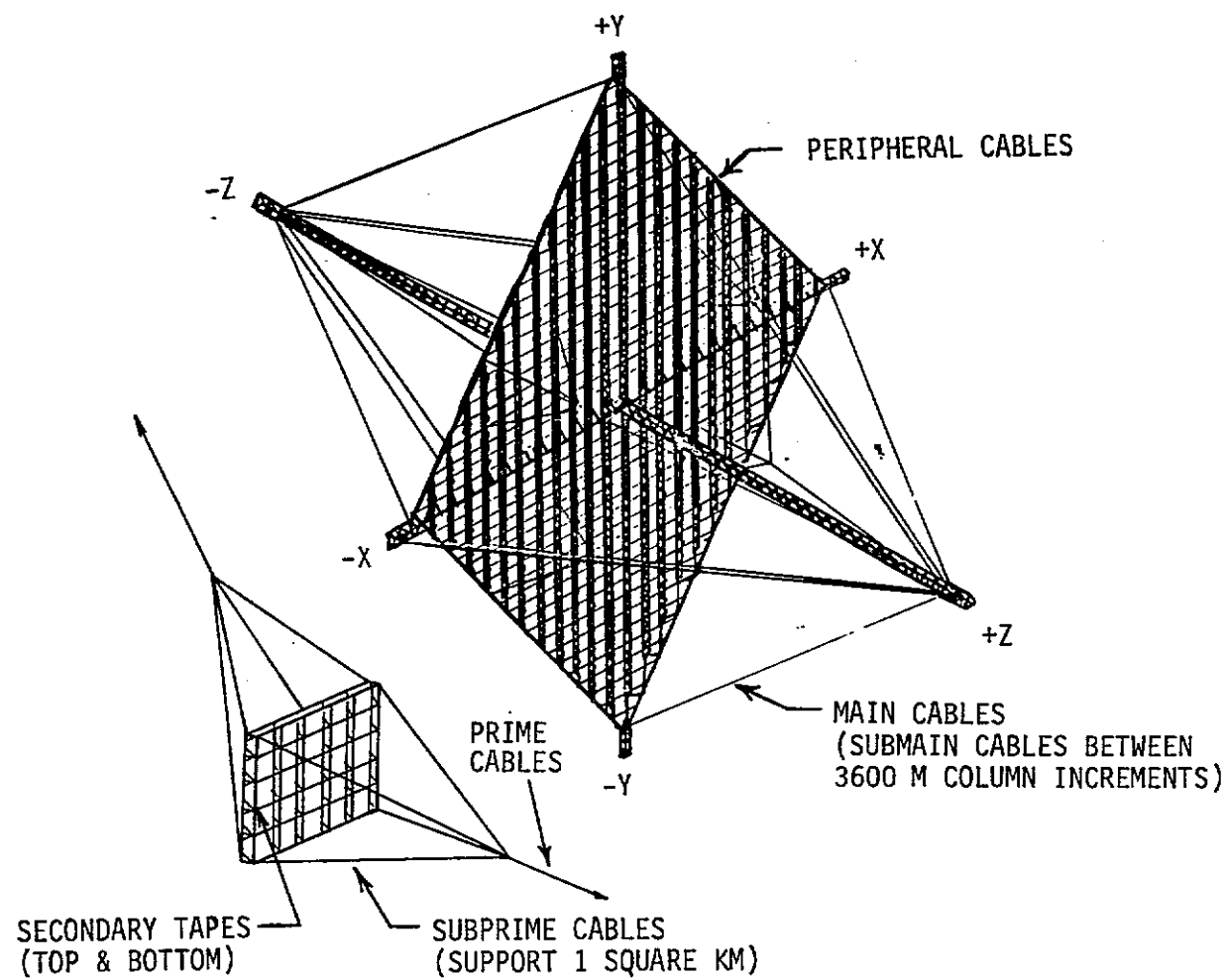


Figure 3.3.1-3 Column/Cable SPS - Cable System Overview

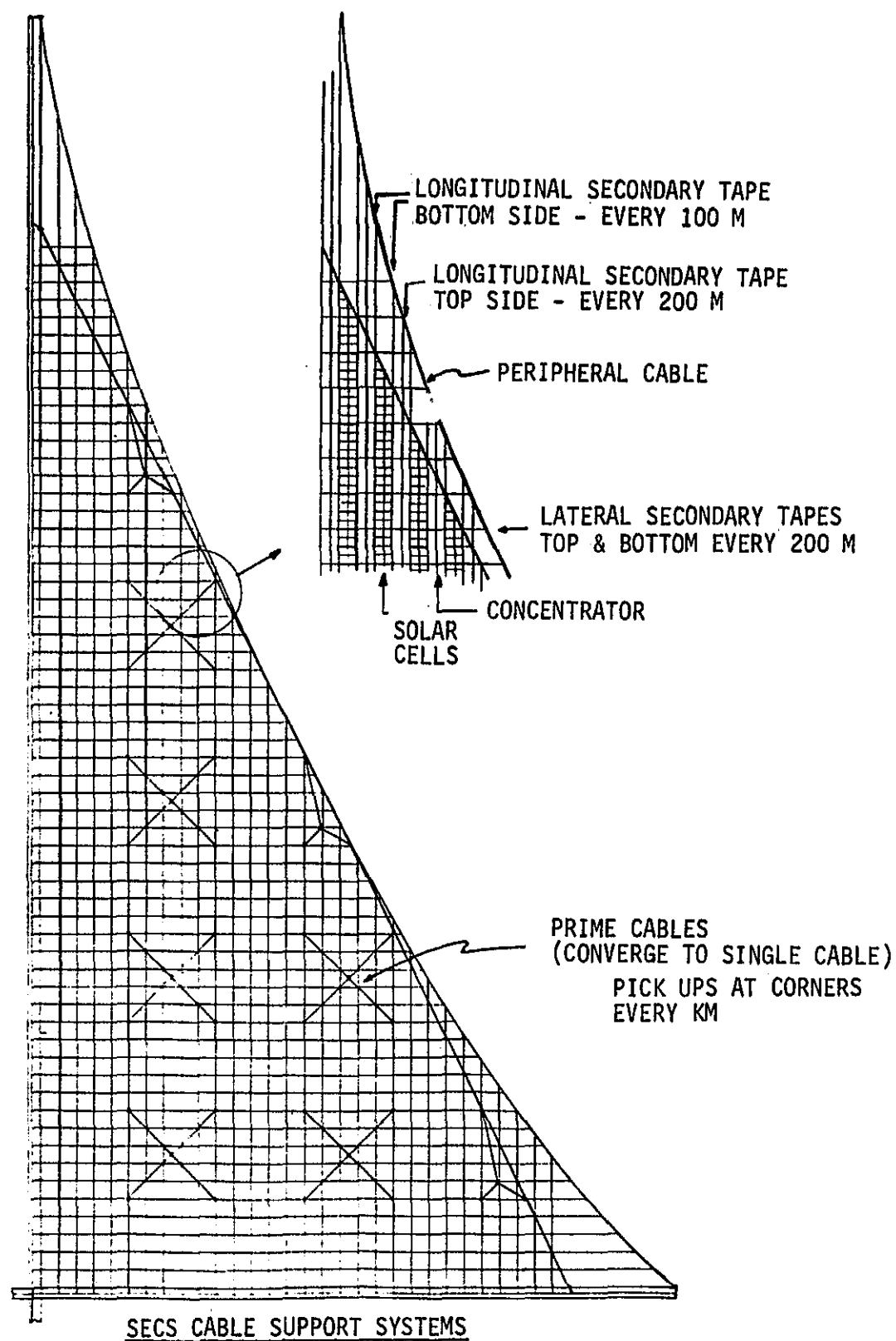


Figure 3.3.1-4 Column/Cable SPS - SECS Cable Support Systems

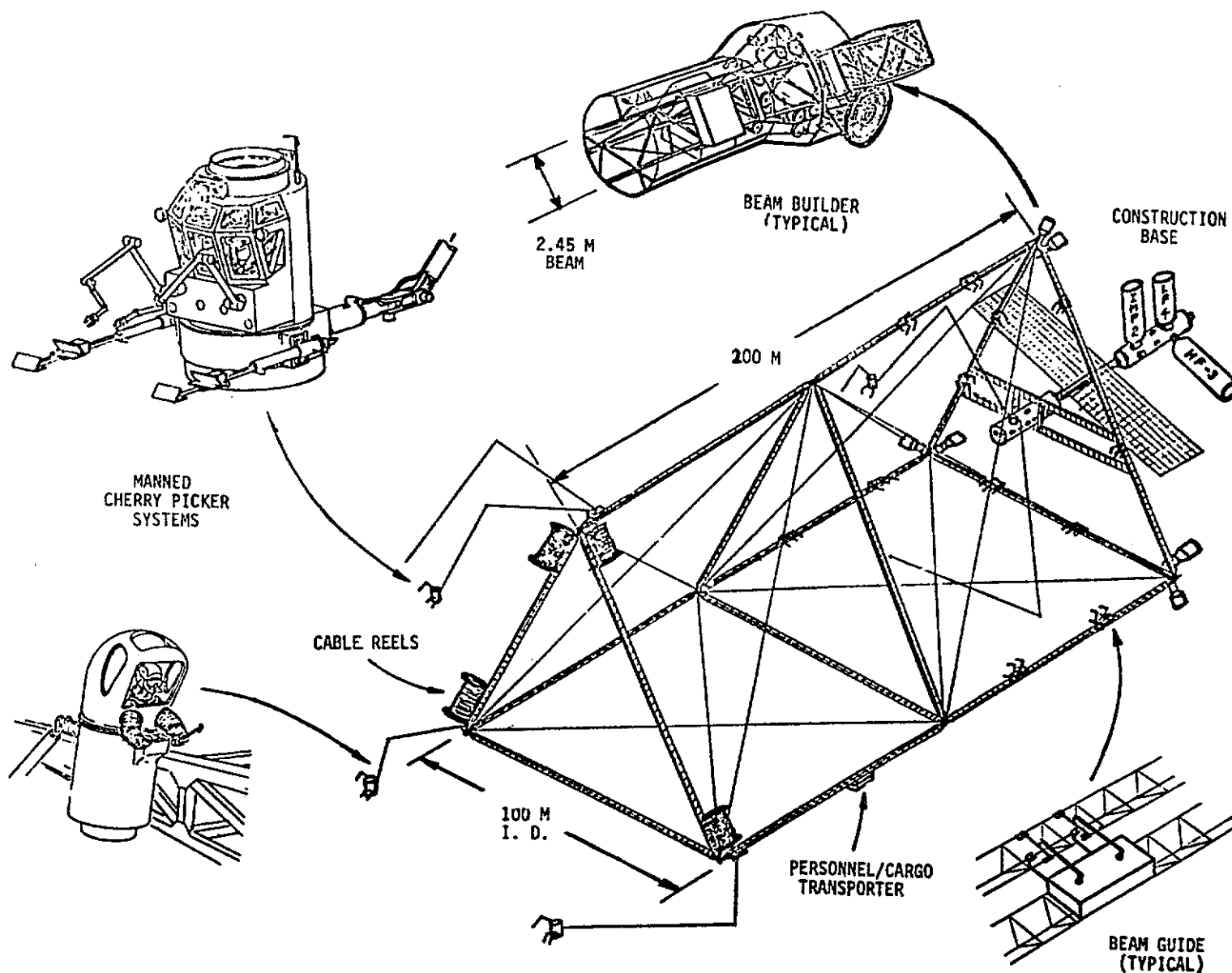


Figure 3.3.1-5 Column/Cable SPS Construction Facility Baseline Concept

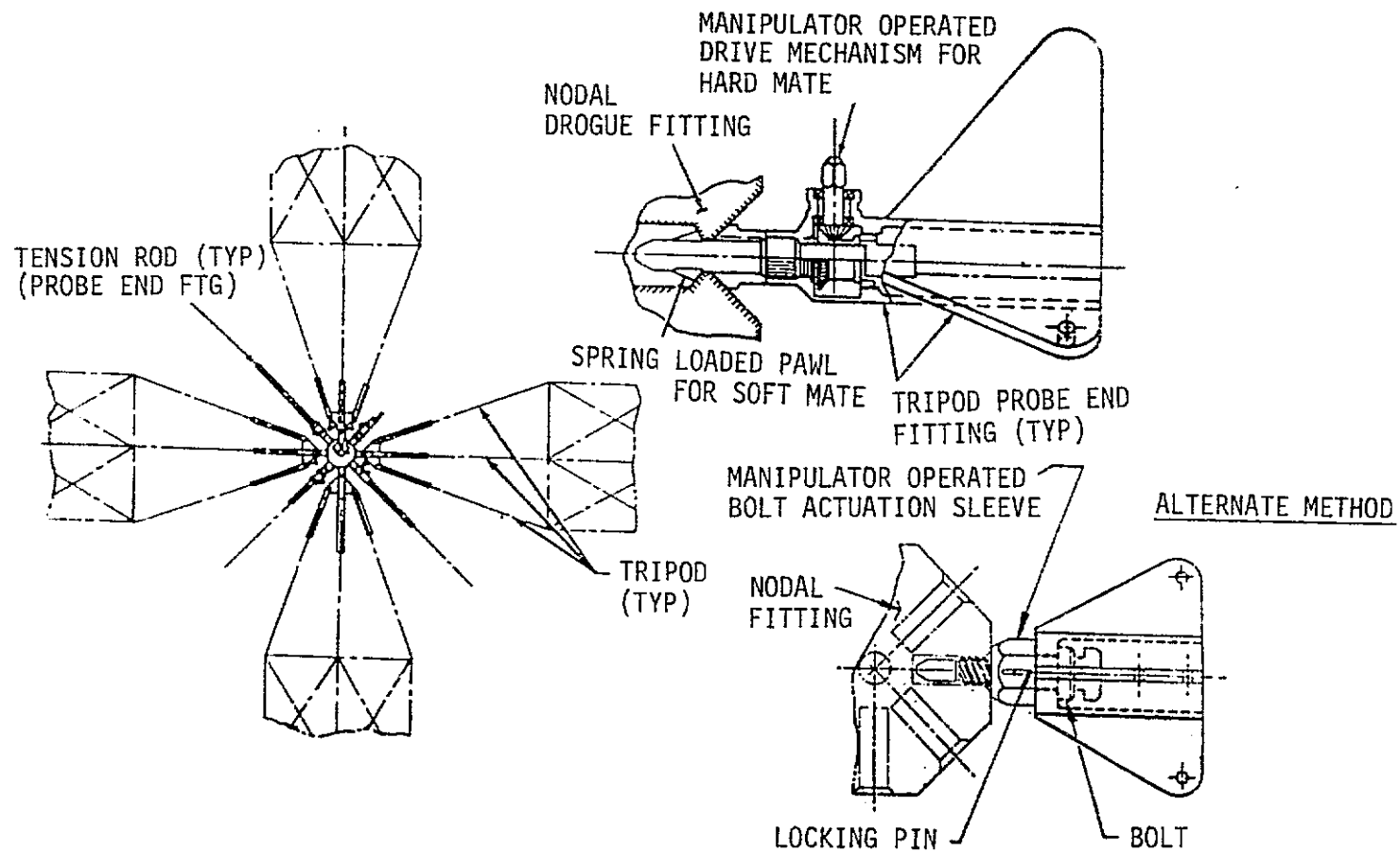
While a 100-meter segment of the column truss is being assembled in the facility outboard bays, concentrator rolls or solar cell panels are installed on the column (exposed from the inboard end of the facility) and connected to the secondary tapes, prime cables, and peripheral cables. When these tasks are completed, the tensions on the main, prime, and peripheral cables are released and each facility is moved outboard 100 meters. These steps are continually repeated until the final SPS configuration is reached. As the peripheral cables move outward from the center, the SECS is pulled out. The SECS is attached to the secondary tapes with rings that allow relative X-Y movement. The secondary tapes are deployed from reels mounted on the +X and +Y columns. All prime cables are carried along by the facilities on the +X columns and the applicable cable ends are attached to the appropriate secondary tape rings at the times of SECS installation.

The column trusses are assembled from 2.45-meter wide triangular beams, 100 meters long, fabricated in automated beam builders (six at each facility). The beams are assumed to have the centroidal node joints shown in Figure 3.3.1-6. Combinations of automated and remote-controlled equipment would install the beams and cross-cables and align the truss by adjustments of beam and cable lengths. The facility structure will provide a jig for aligning the column beams.

Simultaneously during SECS construction, the MPTSS are constructed by equipment operating out of facilities located on structure installed on the outboard side of the +Y column facilities.

It is assumed the facilities would be assembled in low-earth orbit (LEO) and boosted to geosynchronous earth orbit (GEO). There the facilities would be joined at a column hub and the SPS construction would proceed. A manufacturing facility (MF) would be maintained in LEO for assembling and supplying large SPS elements such as MPTS subarrays and secondary structures. To construct the SPS in LEO and subsequently boost it to GEO would, because of the configuration, require low thrust levels and long transit times. This would result in solar cell deterioration in the Van Allen belt and a delay in initiating the operational phase.

When construction is completed and the systems are activated, the construction facilities can be separated and moved to another site for construction of the next SPS. A maintenance facility would be left at the SPS to enable



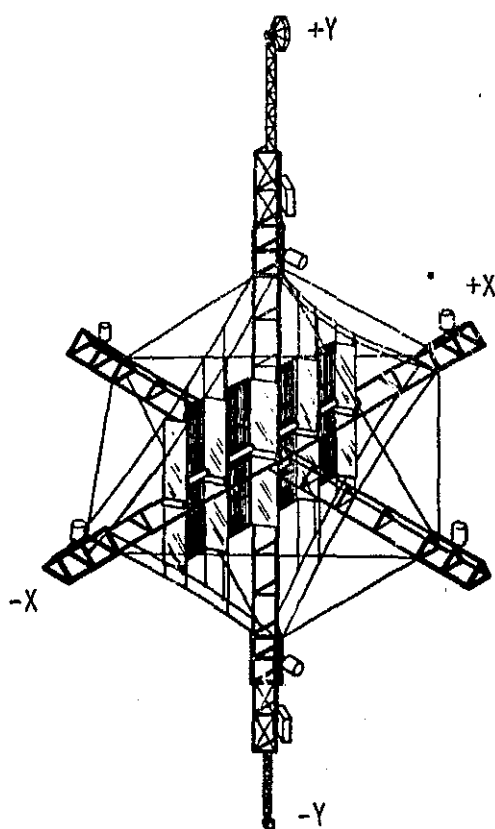
REFERENCE: GRUMMAN CONCEPT

Figure 3.3.1-6 Centroidal Node Joint

performing logistics and maintenance services during the operational period. The functional analysis and construction schedule for the column/cable SPS are presented in Table 3.3.1-1 and Figure 3.3.1-8, respectively. Approximately 70 different construction steps are identified, and over 60 specific equipment requirements were established. These equipment requirements may include logistics, construction equipment or construction support equipment. Other miscellaneous requirements may also encompass these categories of equipment. The maximum and minimum potential uses of man during construction and assembly are also described in the table.

3.3.1.3 C/C Options - Option A to the baseline construction method assumes the column trusses are constructed independently of the SECS installations. The solar cell panels and concentrators are installed by separate construction equipment systems that can move along inside the +X column. The SECS is deployed and attached to the peripheral cables as one of the later construction steps.

Option B assumes solar cells are installed from rolls (Figure 3.3.1-7) instead of the pleated 10 x 10 meter panels depicted in Figure 3.3.1-2.



Since the solar cell weight for the longest trough is about 480,000 kg, several smaller rolls (e.g., 48,000 kg) would be more feasible. The use of rolls permit automating the electrical and mechanical attachments between solar cell segments and with the concentrator sheets. A zipper-like mechanism is envisioned for this joining process.

Figure 3.3.1-7 Column/Cable SPS - SECS Roll Concept Option B

Table 3.3.1-1 Column/Cable SPS Construction - Functional Analysis

TASKS	TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
				MAXIMUM USE OF MAN	MINIMUM USE OF MAN
1.0 ASSEMBLE CONSTRUCTION FACILITIES (LEO)	Light construction facilities will be assembled in LEO and boosted to GEO for subsequent construction of the SPS. These facilities provide the following services: IMF - integration and management facility LF - logistics facility H - habitat CF - construction facility The facilities include: <u>CF-1</u> - IMF + LF + H + CF for constructing the initial SPS hub and one of the main cable support columns. <u>CF-3</u> - LF + H + CF for constructing the other main column. <u>CF-2, CF-4, CF-5, & CF-6</u> - H + CF for constructing the SECS support columns and installing the SECS. <u>CF-7 & CF-8</u> - H + CF for constructing the MPTSs. These are attached to CF-5 and CF-6. In addition, a manufacturing facility (MF-1) will be maintained in LEO for assembling SPS elements too large for direct launch from earth; e.g., MPTS sub-arrays.	Construction base (6)	CF-1 thru CF-6 will provide the capability for assembling triangular beams that are 100 m (328 ft) on a side.		
1.1 Construct CF-1	CF-1 will be initiated with the launch of a construction base with equipment to manufacture triangular beams that are 2.45 meters on a side.	Capability to fabricate 2.45 x 100 m (8 x 328 ft) beams and assemble these into the required facility frame.	- Facility beams will span distances of approx 100 meters. Beam mass is ~36 kg (80 lbs) - Docking provisions are required for subsequent resupply vehicles (materials, consumables, etc). - Beam joining methods are assumed to be the centroidal node joint.	- Make the connections between beams to assemble the facility. - Resupply the beam fabricators. - Perform on-site monitoring of beams to ensure alignments. - On-site operation of manipulators, like earth-operation of cranes. - Maintenance.	- Remote control of OCSE. - Systems remote monitoring. - Fabricator resupply from shirtsleeve environment. - Maintenance.
1.1.1 Launch construction base with beam fabricators	Construction equipment will be installed on the perimeter of the base. The equipment will be used in taking fabricated beams and assembling a large facility frame. This frame will provide hard points and act as a jig for subsequent assembly of the SPS triangular columns that are 100 m on a side. The facility frame is initially conceived as triangular, with inside dimensions of 100 m on a side, and 200 m long to assure straightness of the assembled SPS columns.				
1.1.2 Install construction equipment					
1.1.3 Fabricate facility beams					
1.1.4 Assemble facility frame					
1.1.5 Install auxiliary systems (as required)	Auxiliary systems, such as propulsion, GN&C, etc must be installed if not originally incorporated in construction base.				

Table 3.3.1-1 (Continued)

TASKS	TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
				MAXIMUM USE OF MAN	MINIMUM USE OF MAN
1.2 Construct CF-2, CF-4, CF-5 & CF-6 1.3 Construct CF-3	CF-2 thru CF-6 are essentially like CF-1, in that all build the large 100 m beams. CF-3, like CF-1, provides provisions for storing materials and dispersing them to other facilities. In addition, CF-1 and CF-3 provide the main and prime SPS cables. CF-2, -4, -5, and -6 provide the capabilities for SECS installation: • Solar cell and concentrator packages; • Prime and secondary cables; • Power distribution system.	Same as 1.1	Same as 1.1	Same as 1.1	Same as 1.1
1.4 Construct CF-7 & CF-8	CF-7 and CF-8 build the MPTSS. These facilities are docked to structure outboard of CF-5 and CF-6. These facilities will assemble the 130 x 65 m frames (with cross-cables) used in constructing the MPTS polygon structure. The frame trusses are triangular at 4.3 m on a side. The facility is envisioned as approximately 30 x 70 meters by 150 meters long. Fabricators, OCSE, and jigs are provided in 3 bays for simultaneous manufacture of 3 frames. The same facility will provide support to the equipment for assembling the SECS attachment structure and MPTS substructure and for installing the secondary structure and sub-arrays.	• Capability to fabricate 4.3 x 150 m (14 x 500 ft) beams and assemble these into the required facility frame.	• Facility beams with spans up to 150 meters. • Beam mass is up to ~54 kg (119 lbs). • Docking provisions are required for subsequent resupply vehicles (materials, MPTS elements, consumables, etc).	Same as 1.1	Same as 1.1
1.5 Construct MF-1 1.5.1 Launch facility modules 1.5.2 Assemble facilities 1.5.3 Launch and install facility equipment	The manufacturing facility will be maintained in LEO and will manufacture/assemble SPS elements that are too large for direct earth launch. The facility will contain a crewman habitat, factory-type facility for assembly operations, material stowage area, docking provisions for resupply vehicles, and propellant servicing provisions for orbit-to-orbit vehicles.	• Capability to assemble large habitable vehicle. • Factory-type equipment for assembling specific SPS elements.	• Subarrays = 200 kg. Material packages = TBD kg.	• Hands-on assembly of facility and SPS elements. • Direct machine operation, resupply, and monitoring. • Maintenance.	• Remote control of factory operations from shirt-sleeve environment. • Monitoring of automated equipment. • Machine resupply. • Maintenance.
2.0 BOOST ELEMENTS TO GEO					
2.1 Construction Facilities	As the construction facilities are completed, they will be boosted to GEO. CF-1 will go first, since it must build the SPS hub for CF-2 thru CF-6 to dock to. Since low-thrust propulsion is desirable for these large structures, longer thrust times will be required.				

Table 3.3.1-1 (Continued)

TASKS	TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
				MAXIMUM USE OF MAN	MINIMUM USE OF MAN
2.2 Manned Modules	The construction crews will follow to GEO in manned modules, which will dock to the construction facilities.	• Docking crew transfer provisions.			
2.3 Materials/Consumables	Materials and consumables will be boosted to GEO as required and docked to the logistics facilities at CF-1 and CF-3. From there, smaller transfer vehicles will distribute the commodities to the other construction facilities.	• Cargo transfer vehicles. • Docking and stowage provisions at each CF.	• Cargo distribution distances up to 40 km (25 miles) round trip.	• Fly with cargo vehicles to make the docking maneuvers.	• Remote control piloting of cargo vehicles.
2.4 Prefabricated Elements	Some SPS elements will be manufactured and/or assembled at MF-1 and boosted in large packages to the SPS in GEO.	• Docking and stowage provisions at each logistics facility.		• Direct participation in docking and unloading large cargo	• Remote control and/or monitoring of docking and unloading.
2.5 Crew Exchanges	Construction crews will be exchanged periodically depending on the extent of manned participation and the length of time the crews can stay in GEO. These times will depend on the degree of protection from radiation.	• Manned orbit-transfer vehicle.			
3.0 ASSEMBLE CONSTRUCTION BASE (GEO)	The construction of the SPS starts with all SECS construction facilities joined at the SPS hub and the MPTS construction facilities attached at the outboard ends of structure from CF-5 and CF-6.				
3.1 Construct Hub (CF-1)	CF-1 will construct the SPS column hub. The hub will contain truss stubs to which the other facilities will be attached.	• Same as 1.1 • Basic CF-1 equipment appears sufficient to enable building the hub structure.	• Same as 1.1 • Truss stubs will be installed after the column has cleared the facility.	• Same as 1.1	• Same as 1.1
3.2 Start Column Construction (CF-2 thru CF-6)	Prior to joining the facilities, the construction of the columns will be started in each facility. When the columns reach the point of protruding from the facilities, they will be docked and joined to the hub built by CF-1.	• Same construction equipment • Capability to hold facilities together while contact points are joined.			
3.3 Dock CF-2 thru CF-6 to Hub (at Truss Stubs)					
3.4 Dock CF-7 & CF-8	Column structure will also be built at the outboard ends of CF-5 and CF-6 to provide attachment points for the MPTS attachment structures. These column structures will be attached to the CF-5 and CF-6 facility structure. CF-7 and CF-8 will be docked				

Table 3.3.1-1 (Continued)

TASKS	TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc.)	MAN'S ROLE	
				MAXIMUM USE OF MAN	MINIMUM USE OF MAN
3.4 (Continued)	and attached to the sides of these column extension structures. Therefore, these structures must be able to take side loads also (no longer only compression as with the SECS main column use).				
4.0 CONSTRUCT SPS					
4.1 Construct SECS	CF-1 thru CF-6 build the SECS. CF-1 and CF-3 build the main cable support columns, perpendicular to the solar arrays. CF-2, -4, -5 and -6 build the solar array support columns. Installation of all SECS elements take place in the vicinity of the facilities. As assembly takes place, all facilities progressively move further apart.				
4.1.1 Build continuous columns (6 places)	Fabricators in each facility will build triangular beams (2.45 m on a side) that are 100 m long. These beams will be assembled to form the continuous SECS columns (100 m on a side). After each 100 m segment is assembled, the facility is moved outward from the SPS center. Then the procedure is repeated to build the next 100 m column segment in the empty facility bay.	• Capability to fabricate 2.45 x 100 m (8 x 328 ft) beams and assemble these into the 100 m wide columns.	• Beams will span 100 meters. Beam mass is ~36 kg (80 lbs). • Beams are joined by probe and drogue centrodal node joints.	• Make connections between beams to assemble the columns • Resupply the beam fabricators. • Perform on-site monitoring of beams to ensure alignments. • Work-site direct operation of manipulators • Maintenance.	• Remote control of construction equipment. • Systems monitoring. • Fabricator resupply from shirtsleeve environment. • Maintenance.
4.1.1.1 Build trusses					
4.1.1.2 Assemble trusses to extend columns					
4.1.2 Install cable systems	Cable systems maintain the rigidity of the SECS. Main cables between the facilities maintain the columns in compression. Cables from CF-1 and CF-3 to the solar arrays provide the prime support for the arrays. Secondary cables (tapes) in a grid pattern also support the solar arrays (top and bottom). These secondary cables are attached between the SECS columns and peripheral tension cables between facilities. Submain cables interconnect the columns at 3600 meter increments.				
4.1.2.1 Attach and deploy main cables between CFs	When the facilities are joined at the hub, cables are attached from CF-1 and from CF-3 to each of the other 4 facilities. These cables are fed out from CF-1 and CF-3 as required, as the SECS expands. The cables are maintained at 3000 Newtons tension (675 lbs). The submain cables are permanently attached and tensioned when the 3600 meter distances are reached on the columns.	• Main cable deployment and tensioning reels (8). • Capability to attach main cables between facilities and columns	• Cable lengths are about 16.3 and 20.5 km (10.1 and 12.7 miles)	• Direct attachment of cable ends. • Operation of reels when facilities are moved at each 100 m increment.	• Remote control attachment of cables. • Periodic inspection and servicing of automated reel

Table 3.3.1-1 (Continued)

TASKS	TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
				MAXIMUM USE OF MAN	MINIMUM USE OF MAN
4.1.2.2 Attach and deploy peripheral tension cables	Peripheral cables are attached between CF-2 and CF-5, CF-2 and CF-6, CF-3 and CF-5, and CF-3 and CF-6. There are two cables at each place. The top (sun-side) cable pulls on the top secondary SECS support tapes. The bottom cable pulls on the bottom (anti-sun) secondary tapes. These cables are attached at CF-5 and CF-6 and fed out as required from CF-2 and CF-4. The cables are maintained at 3000 N tension.	Peripheral cable deployment and tensioning reels (4 each at CF-2 and CF-4).	Cable lengths are about 19 km (12 miles each).	- Direct attachment of cable ends. - Operation of reels.	- Remote control attachment of cables. - Periodic inspection and servicing of automatic reels.
4.1.2.3 Attach and deploy solar-cell support prime cables	Prime SECS support cables are attached at the corners of alternate square kilometers of the solar arrays. These four cables (3 at some places at the edge of the SECS) join and a single cable continues to CF-1 and CF-3. These cables (36 sets) are initially deployed from CF-1 and CF-3 and the ends are carried along by CF-2 and CF-4. When the appropriate solar cell packages are installed, the corresponding prime cables are attached to the secondary tapes.	- Prime cable deployment and tensioning reels (36 each at CF-1 and CF-3). - Capability to attach prime cable ends to SECS packages.	Prime cable deployed lengths are up to 15.5 km (9.6 miles).	- Direct attachment of cable ends. - Operation of reels.	- Remote control attachment of cables. - Periodic inspection and servicing of automatic reels.
4.1.2.4 Attach secondary tapes to SECS columns and peripheral cables	As the SECS is assembled in the +X direction (CF-2 and -4), the longitudinal tapes (+Y) are installed between the +X column and the peripheral cable. The installation includes reels installed each 200 meters on the top of the column for the top (sun-side) tapes and reels each 100 meters on the bottom. Each reel contains the required length of tape to provide the necessary final SECS configuration. All secondary tapes for the +X directions are installed at the hub during initial operations. These tapes are attached between the hub and the +X facilities (CF-2 and CF-4). Again reels are used to allow the tapes to extend as the +X dimension increases. Periodically, the tape ends are attached to the peripheral cable such that in the final deployed position, the tapes are 200 meters apart. Tapes are provided on both the sun and anti-sun sides. The reels are allowed to move along the +Y columns as the structure expands in the +Y direction.	- Secondary tape deployment and tensioning reels for the +Y direction (360 reels). - Secondary tape deployment and tensioning reels for the +X direction (480 reels).	- Tape lengths (+Y) from 1.4 to 14.4 km. - Reels automatically tensioned to 22 N (5 lbs). - Tape lengths (+X) from 0.6 to 7.0 km. - Reels automatically tensioned to 22 N (5 lbs).	- Direct attachment of tapes to peripheral cables. - Direct installation of tape reels. - Movement of tape reels along +Y columns.	Remote control attachment of tapes and reels.
4.1.2.5 Tension individual cables (as required)	The secondary tapes will be automatically maintained at 22 N tension by the reels. However, the prime, peripheral and main cable reels will be released (in pairs) when the facilities are moved outwards in 100 meter increments. When the facilities reach the next position, the cables will be retensioned and locked up. Thus, disturbances to the structure will result in loading up a cable and the return of the structure to the neutral (equal cable tension) position.	Tension read-out measurements on the prime, peripheral and main cable reels.		Operation of reels for unlock and retensioning of cables.	Initiate reel operations from central console (reels are automatically maintained in balance across the SPS) and standby for contingencies.

Table 3.3.1-1 (Continued)

TASKS	TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
				MAXIMUM USE OF MAN	MINIMUM USE OF MAN
4.1.3 Install solar energy collection system (SECS)	When CF-2 and CF-4 move outward (+X) 100 meters, a new set of solar cell packages or concentrator packages are installed. These packages are pleated and will be deployed by pull on the secondary tapes from the peripheral cable. The packages are 10 x 10 meters on the side and up to 8 meters in depth. The packages are installed in rows of 10 to span the 100 meter distances.	• Capability to move packages to the installation sites.	• Package sizes 10 x 10 x 8 m (33 x 33 x 26 ft) • Weight: solar cells = 48,000 kg (106,000 lbs) maximum package. concentrators = 5000 kg (11,000 lbs) maximum package	• Direct attachment of SECS packages.	• Remote control of construction equipment.
4.1.3.1 Attach pleated solar cell and concentrator packages at support columns	The SECS packages (10 x 10 x 8 m) will be attached at the column and by rings to the secondary tapes. The rings allow relative movement of the tapes, as they are deployed.	• Capability to attach the packages to the column.			
4.1.3.2 Attach packages to secondary tapes		• Capability to hook the rings on the secondary tapes.			
4.1.3.3 Attach prime cables to SECS packages	The prime cables will be carried outward with CF-2 and CF-4. As the set of packages that fall at the corner of alternate square kilometers are installed, one of the subprime cables will be installed to the package ring.	• Capability to move subprime cable from facility to package ring and attach it.		• Direct movement and attachment of cable.	• Remote control of construction equipment.
4.1.4 Install power distribution system	The concentrator sheets (aluminumized) are assumed to conduct the power in the column/cable SPS since truss structure is minimal. The solar cell packages must be interconnected electrically and connected electrically to the concentrator panels. The concentrator sections must also be electrically interconnected. These connections could be made at the construction facility but probably would be more adaptable to being made at the time of installation on the main column. Transition conductors between the concentrators and the conductor cables (peripheral cables) will be connected at the time of SECS package installations.	• Capability to electrically interconnect solar cell and concentrator segments. • Capability to connect transition conductors to peripheral cables		• Direct connections of solar cells and concentrators. • Direct connections of conductors	• Automatic machines or devices to interconnect segments as they are deployed. • Remote control of construction equipment.

Table 3.3.1-1 (Continued)

TASKS	TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
				MAXIMUM USE OF MAN	MINIMUM USE OF MAN
4.1.4 (Continued)	The peripheral conductor cables (main bus) will be interconnected and connected to the MPTS conductors after the SECS is totally assembled.	• Capability to connect peripheral cables to MPTS conductors		• Direct connection of conductors.	• Remote control of construction equipment.
4.1.5 Install auxiliary equipment	All auxiliary equipment will be installed at the ends of the main columns. It is anticipated that CF construction equipment could handle the transfer and installation of the auxiliary equipment to the column prior to removing the facilities.				
4.1.5.1 Attitude control systems	MPD arc jet engines (48) used for attitude control.	• Capability to install systems	• Total weight 313,000 kg (includes 200,000 kg for 1 year of propellants)	• Direct installation and connections of systems.	• Remote control of construction equipment.
4.1.5.2 Instrumentation and communications systems	Systems include computer, data management, and TT&C.	• Capability to install system	• Total weight 4,000 kg.		
4.1.5.3 Counterweights	Counterweights at the ends of the +Z column are advantageous if the high-specific impulse RCS cannot be developed.	• Capability to transfer and install large masses.	• $\sim 5 \times 10^5$ kg each.		
4.2 Construct MPTS (2)	An MPTS at each end of the +Y column converts DC power to microwave energy and transmits it to earth. Each antenna contains 7854 10 m x 10 m subarrays on a supporting structure. Each subarray is an integral unit containing microwave generators (klystrons or amplifiers), a slotted waveguide front face and control electronics. A ball joint allows each antenna to be pointed as required toward the ground receiving antenna. CMGs under computer control are utilized to accomplish pointing. A counterweight system is used to equalize moments of inertia about all axes and eliminates gravity gradient torques. Phase control, power distribution and pointing control systems are interconnected by electrical conductors or waveguides between subarrays or groups of subarrays for overall MPTS control. These systems are mounted within the antenna structure behind the subarrays.		• 1 km dia x 72 m depth (structure)		

Table 3.3.1-1 (Continued)

TASKS	TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
				MAXIMUM USE OF MAN	MINIMUM USE OF MAN
4.2.1 Build MPTS support structure	The MPTS extension support structure connects the antenna itself with the main body of the SECS. This structure is made up of triangular beam sections. Interfacing structure between this extension structure and the ball joint frame is also attached (accommodates differences in geometry between ball joint frame and support structure). Electrical conductors which carry the DC power from the SECS over the extension structure are also installed at this time.	• Capability to fabricate and assemble support structure beams, interface structure • Capability to string and attach electrical conductors (~1 km in length). • Method to transfer material from fab facility outward along support structure	• Extension structure ~750 m length for column/cable SPS. • 66 beams @ 65 m long; 4 @ 35 m (4.3 m triangular).	• Make connections between beams to assemble structure. • Resupply beam fabricators. • Perform on-site inspection and monitoring of beam joints, electrical conductor attachments. • Manipulator operation.	• Remote control of construction equipment. • Remote systems monitoring. • Resupply and manipulator operations from shirt-sleeve environment.
4.2.1.1 Build extension structure					
4.2.1.2 Build ball joint frame-to-support structure interface					
4.2.1.3 Install electrical conductors (ball joint frame to SECS)					
4.2.2 Install ball joint	The ball joint is delivered to GEO as a unit and mechanical and electrical connections are accomplished at the construction site. First, the ball joint is attached to the support structure interface. Six support arms are built outward from the ball joint. (These arms provide attachment points for the first concentric ring of the main MPTS substructure; see step 4.2.3.1.) Then electrical connections are made between the frame conductors (step 4.2.1.3 above) and the ball joint power input bus; additional connections are accomplished between the joint output bus and the ball joint frame conductors (which eventually connect to the MPTS itself). The ball joint is locked in place to prevent inadvertent rotation during MPTS construction.	• Manipulator to put ball joint in place. • Attachment mechanism. • Capability to string and attach electrical conductors (~10 m length)	• Ball joint - 11 m in diameter. • 2 @ 165 m, 50 @ 65 m; 4 @ 150 m (5.5 m triangular)	• Manipulator operation • Electrical conductor attachment.	• Remote operation, monitoring.
4.2.2.1 Attach frame to support structure					
4.2.2.2 Build support arms					
4.2.2.3 Install electrical conductors from frame to ball joint bus					
4.2.3 Assemble MPTS substructure	Fabrication and assembly of the MPTS structure begins after the ball joint is in place. The fabrication facility is located at the base of the support structure (near the SECS construction facilities). Assembly is accomplished at the antenna site, working from the center outward in concentric rings of structure. The first ring is a hexagon formed by six rectangular frames (65 m high x 130 m long). Frame members are triangular beams 4.3 m on each side. Six other frames are used to form six equilateral triangles within the ring. The six outside frames are attached to support arms assembled in step 4.2.2.2. Cables are attached to support each frame and to rigidize the hexagon formed by the frames.	• Methods to transfer material from fab facility over support structure to antenna. • Capability to attach and apply tension to cables. • Capability to assemble frames, connect frames together,	• Triangular frame beams - 4.3 m on a side by 65 m and 130 m long (12 required). • Attachment beams (ball joint to base of first ring frames) 100 m long each (6). • 24 frame cables ~146 m long.	• Direct control of frame assembly, attachment and structure assembly. • Direct control of cable tensioning.	• Remote monitoring of automatic manipulator process; inspection of joints.
4.2.3.1 Build first concentric ring					

Table 3.3.1-1 (Continued)

TASKS	TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
				MAXIMUM USE OF MAN	MINIMUM USE OF MAN
4.2.3 - 4.2.3.1 (Continued)		connect first ring to ball joint attachment beams.			
4.2.3.2 Install secondary structures	Secondary structures, fabricated and assembled at a separate location, are mounted on the top surface of the hexagon which constitutes the first concentric ring. These secondary structures are triangular (130 m on each side, 7 m in depth) and their internal structure forms a rectangular grid on the top surface of the antenna. These structures are attached at three points to the main structure frames, and are delivered to the construction site folded up to be deployed as required for attachment. Deployment is automatic (i.e., popout). Six secondary structures are required for the first concentric ring of the antenna. Surface flatness is measured and adjusted as required.	• Transport method for secondary structures. • Manipulator, attachment techniques. • Alignment measurement and adjustment technique.	• Six secondary structures. - Dimensions (folded): TBD • ~1200 kg (2640 lbs each)	• Deployment of secondary structure, attachment of secondary structure to main frames using manipulators. • Direct control of flatness adjustments.	• Monitoring of secondary structure deployment; monitoring of attachment procedure; inspection of surface flatness.
4.2.3.3 Build second concentric ring	Once the first concentric ring is completed, assembly of the second concentric ring can begin. The same basic types of rectangular frame structure and supporting cables are utilized. Additional radial cables are used to tie the second ring to the first and, once the frame of the second ring is complete, circularize and rigidize the structure. As successive frames are attached to each other, and initial cable attachments made to the first ring, the incomplete second ring must be supported and held in the proper position.	• Same as 4.2.3.1 and 4.2.3.2. • Support arms to hold second ring frames in place while mating frame is attached and radial cables attached. • 4.2.3.4 same as 4.2.3.3	• Triangular frames 130 m x 65 m (12 required). • Frame cables (24 required) ~146 m long. • Radial cables (36 required) 12 @ 150 m each 24 @ 175 m each. • 18 secondary structures (2nd ring). • 3rd ring (18 frames); 30 sec. structures; 36 frame cables @ 146 m each; 48 radial cables @ 175 m each; 12 radial cables @ 150 m each. • 4th ring (24 frames); 42 sec. structures; 48 frame cables @ 146 m; 72 radial cables @ 175 m; 12 radial cables @ 150 m.		
4.2.3.4 Build third and fourth concentric rings	Eighteen secondary structures are mounted to the top surface of the second concentric ring; these structures are similar to those utilized for the first ring in that they "popout" for deployment and are attached at three points, but the shapes vary to accommodate ring geometry. Additional rings are built outward of 18 and 24 sides each, to achieve 1 km diameter.				

Table 3.3.1-1 (Continued)

TASKS	TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
				MAXIMUM USE OF MAN	MINIMUM USE OF MAN
4.2.4 Install subarrays	Subarrays (10 m x 10 m ea) are nonstructural elements which contain the power conversion and transmission equipment. Each antenna contains 7854 subarrays, which are mounted on the top surface of the secondary structure. The subarrays are fabricated in a separate facility (MF-1) and transported to the antenna construction site. Each subarray contains microwave generators (klystrons or amplifiers), a waveguide system for phase control, power distribution system wiring and an electronics package, all mounted beneath the slotted waveguide front face through which the microwave energy is transmitted. The subarrays are attached to the secondary structure at three points. They can be mounted as each concentric ring is completed or immediately after each secondary structure is installed (before other secondary structures are in place), or subarray installation can be accomplished after the entire antenna structure is complete.	- Transfer method for subarrays from fab facility to secondary structure surface. - Attachment technique.	7854 10 m x 10 m subarrays. 156 to 240 kg (343 to 528 lbs) per subarray.	- Attachment of individual subarrays to secondary structure. - On-site inspection, monitoring.	Remote inspection.
4.2.4.1 Fabricate subarrays					
4.2.4.2 Mount subarrays on antenna secondary structure					
4.2.5 Install phase control system	Since each microwave generator acts as a separate radio transmitter, phase information must be available to each generator so that system efficiencies are optimized. This is accomplished via an RF signal sent from the ground to the MPTS, which is transferred through the subarrays to each microwave generator. For phase control, the subarrays are interconnected in series, with 8 to 16 subarrays per group. The subarrays in each group are connected electrically (waveguides or wires). This interconnection is accomplished through the electronics packages, and can be done at any time after the subarrays in any concentric ring are mounted on the secondary structure or after all subarrays are mounted in the MPTS.	Electrical conductor connections between subarrays (waveguides or wire connectors).	Electrical conductor length in 10 m increments.	On-site placement and attachment of conductors between electronics packages.	Remote inspection of connections.
4.2.5.1 Interconnect electronics packages between subarrays					
4.2.5.2 Install RF lines from reference subarrays to subarray groups		RF transmission line attachment mechanism.	~700 RF transmission lines, max length = 500 m.	Placement and attachment of lines to subarrays (both sides).	Attachment of lines at subarray end, after initial attachment of lines as part of that subarray group fabrication.

Table 3.3.1-1 (Continued)

TASKS	TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
				MAXIMUM USE OF MAN	MINIMUM USE OF MAN
4.2.5.2 (Continued)	completed as soon as the outer subarray groups are placed. Alternately, the transmission lines can be attached as a single task after all subarrays have been mounted in the MPTS.				
4.2.6 Install power distribution system	The microwave energy transmitted to earth from the MPTS is that energy collected by the SECS, transferred to the MPTS as DC power over the ball joint and distributed to each microwave generator. Each subarray, as mounted in the secondary structure (step 4.2.4.2), contains the wiring for power distribution from the electronics package within the subarray to each microwave generator.	• Transfer technique to carry switch gears to antenna. • Electrical conductor attachment method.	• 16 switch gears 2000 kg (4400 lbs) each. • Conductor length switch gears to ball joint bus: 4 @ ~600 m; 4 @ ~500 m; 4 @ ~400 m; 4 @ ~300 m. • Conductor length switch gears to dist. pts (main lateral path): 4 @ 500 m; 4 @ 400 m; 4 @ 300 m; 4 @ 200 m; plus ~1000 wires avg length 100 m. • Intersubarray wiring 10 m increments, max length 30 m.	• Installation and attachment of switch gears • Installation and attachment of wiring from switch gears to ball joint bus. • Installation and attachment of wiring to dist. pts. • Installation and attachment of wiring between subarrays	• Monitoring/inspection of wiring connections, switch gear attachments.
4.2.6.1 Install switch gears					
4.2.6.2 Attach electrical conductors from ball joint bus to switch gears	Sixteen switch gears are required, mounted in two rows of eight along the antenna axis, as the interface between the power from the SECS and the individual subarrays. These switch gears are attached to the antenna structure within the secondary structure.				
4.2.6.3 Install electrical conductors from switch gears to distribution points	Electrical conductors are then attached from the switch gears to the ball joint bus (4.2.2.3). These lines would be placed along the antenna structure radially to the antenna center, then axially (elevation joint axis) to the ball joint bus.				
4.2.6.4 Install electrical conductors at distribution points between subarrays	Electrical conductors are also placed laterally from each switch gear to distribution points in each antenna quadrant. Each switch gear services between 100 and 400 distribution points depending upon its location on the axis. Depending upon the distance from the antenna center, these distribution points transfer power to one, two, or four subarrays. Wiring between subarrays at such distribution points must also be placed.				
4.2.7 Build counterweight system	Because the antenna structure is relatively massive, a counterweight system must be employed. Since the counterweight must be located on the side of the ball joint opposite the antenna mass, a cone-shaped support structure must be built. The support structure is composed of 24 beams extending from the circumference of the antenna structure back to a single point. The counterweight (including the CMGs) must be assembled at the apex of the cone.	• Support structure beam assembly and attachment. • Transfer of counterweight.	• Support structure beams - 120 beams @ 150 m long ea; 5.5 m triangular • Counterweight ~10⁶ kg (2.2 x 10⁶ lbs).	• Support structure assembly with manipulators. • Placement of counterweight with manipulator.	• Inspection of support structure joints. • Monitoring of counterweight placement.
4.2.7.1 Build cone support structure					
4.2.7.2 Fab/assemble counterweight					
4.2.7.3 Attach counterweight at cone apex (including CMGs)					

Table 3.3.1-1 (Continued)

TASKS	TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
				MAXIMUM USE OF MAN	MINIMUM USE OF MAN
4.2.8 Install pointing control system	A control signal sent from the ground to the MPTS is used to measure pointing errors, and computer-controlled CMGs are used to correct such errors. The computer is mounted near the center of the antenna within the structure. Two control moment gyros (part of counterweight system, step 4.2.7) point the antenna. Finally, interconnecting wiring between the CMGs and the computer, and between the computer and seven reference subarrays used to measure pointing errors must be installed.	- Equipment to transfer computer to antenna and attach computer to structure. - Equipment to transfer CMGs along antenna axis and attach CMGs to structure. - Equipment to string and connect wiring between CMGs, ref subarrays and pointing computer.	- Computer size - TBD. - CMGs ~ 25,000 kg (55,000 lbs) each. - Wiring lengths 3 @ ~ 75 m; 2 @ ~ 200 m; 2 @ ~ 300 m, CMGs to computer ~ 625 m.	- Computer attachment, installation and attachment of CMGs. - Installation and connection of wiring.	- Inspection of electrical wiring connections. - Monitoring of computer and CMGs mounts.
4.2.8.1 Mount computer in antenna structure					
4.2.8.2 Install wiring					
5.0 ACTIVATE SPS	The following tasks are required to complete the construction activities and make the SPS operational.				
5.1 Complete Column Attachments to the MPTS Extension Structure	Portions of the CF-5 and CF-6 structures are left in place and permanently attached to the columns to provide a hard joint with the MPTSs.				
5.2 Final Alignments	Verify all alignments. Adjust main cables and peripheral cables as required, to assure perpendicularity of main columns. Adjust prime cables, as required, to make solar arrays flat.	Laser sighting devices.			
5.3 Activate Attitude Control Systems	The attitude control systems will be activated and checked out.	Systems C&D area in CF-1.		Systems monitoring and control.	
5.4 Orient SPS to POP and Solar Orientation	The SPS will be maneuvered to the desired orientation.			Systems monitoring and control.	
5.5 Unlock MPTS Joints, Activate CMGs, and Point MPTSs	The MPTS joints will be unlocked (see 4.2.2). The CMGs will be activated. The MPTSs will be pointed and the automatic steering control system will be activated.			Systems monitoring and control.	
5.6 Checkout Subsystems	All SPS subsystems will be checked out before and after activating the SPS power systems.				

Table 3.3.1-1 (Concluded)

TASKS		TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
					MAXIMUM USE OF MAN	MINIMUM USE OF MAN
5.7 Detach and Remove Construction Facilities		After the SPS is operational and verifications are complete, the construction facilities are removed and maneuvered to other construction sites.	• Capability to disassemble facilities as required.		• Direct disassembly activities.	• Remote control of construction equipment.

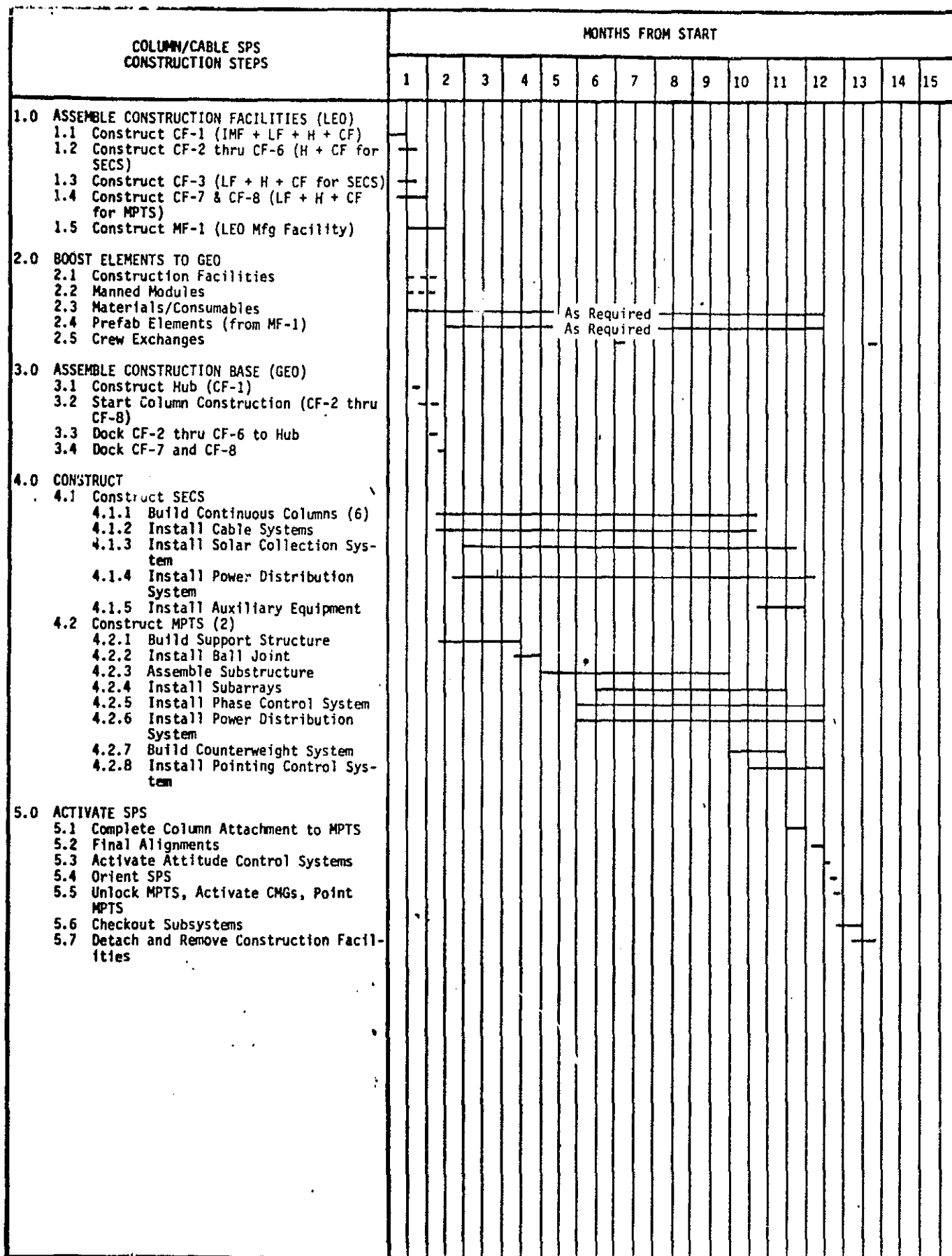


Figure 3.3.1-8 Column/Cable SPS Construction Timelines

3.3.2 Solar Photovoltaic Truss-Type SPS

3.3.2.1 Overview - The JSC concept of the truss configuration (T) SPS is presented in Figure 3.3.2-1. The support structure is comprised of four main longitudinal trusses, connected by transverse beams. The longitudinal trusses are 650-meter wide triangular trusses assembled from 10-meter wide triangular beams. The SECS is comprised of 650-meter wide solar cell panels and aluminized concentrator sheets (Figure 3.3.2-2). Electrical power is transmitted from each half of the SECS, through the concentrators, to power distribution cables at the end walls, and then to an MPTS at each end of the SPS.

3.3.2.2 Construction Activities - The baseline construction method for the truss SPS assumes the main support trusses are assembled in segments in the outboard bays of the construction facility, similar to the method discussed for the C/C SPS. A facility concept is shown in Figure 3.3.2-3. The solar cells and concentrators are installed as the completed structure is moved out of the facility. Figure 3.3.2-4 presents an inboard view of the facility showing the SECS installers. The solar-cell and concentrator strips are mechanically and electrically connected by automatic zipper systems. Top transverse beams are installed after the appropriate truss attachment points have cleared the facility.

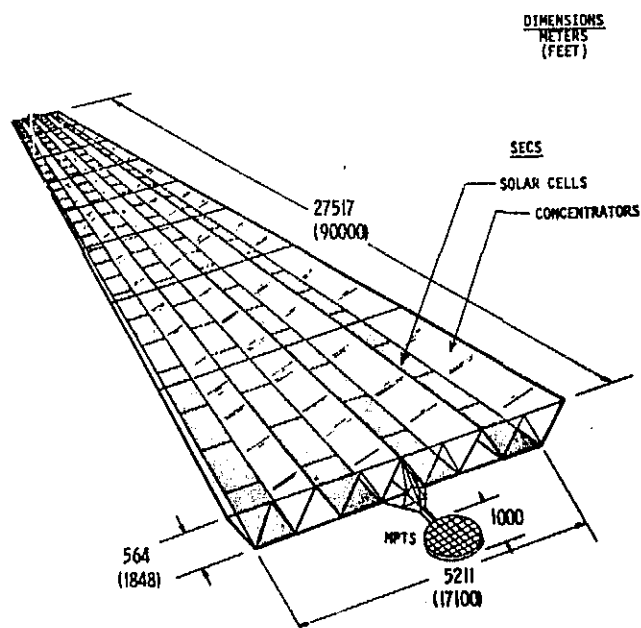


Figure 3.3.2-1 Truss Type SPS

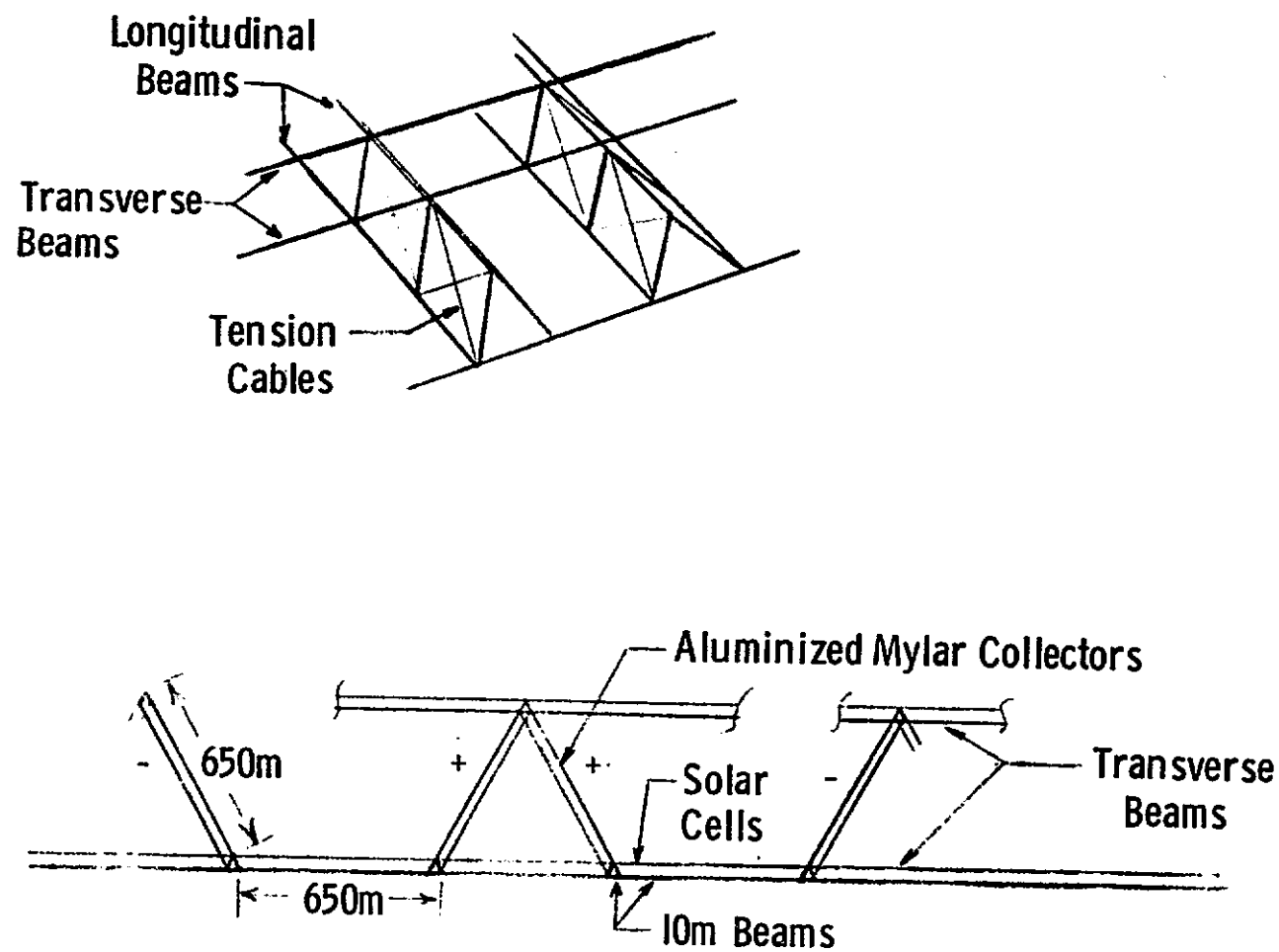


Figure 3.3.2-2 Truss Type SPS - Solar Energy Collection System

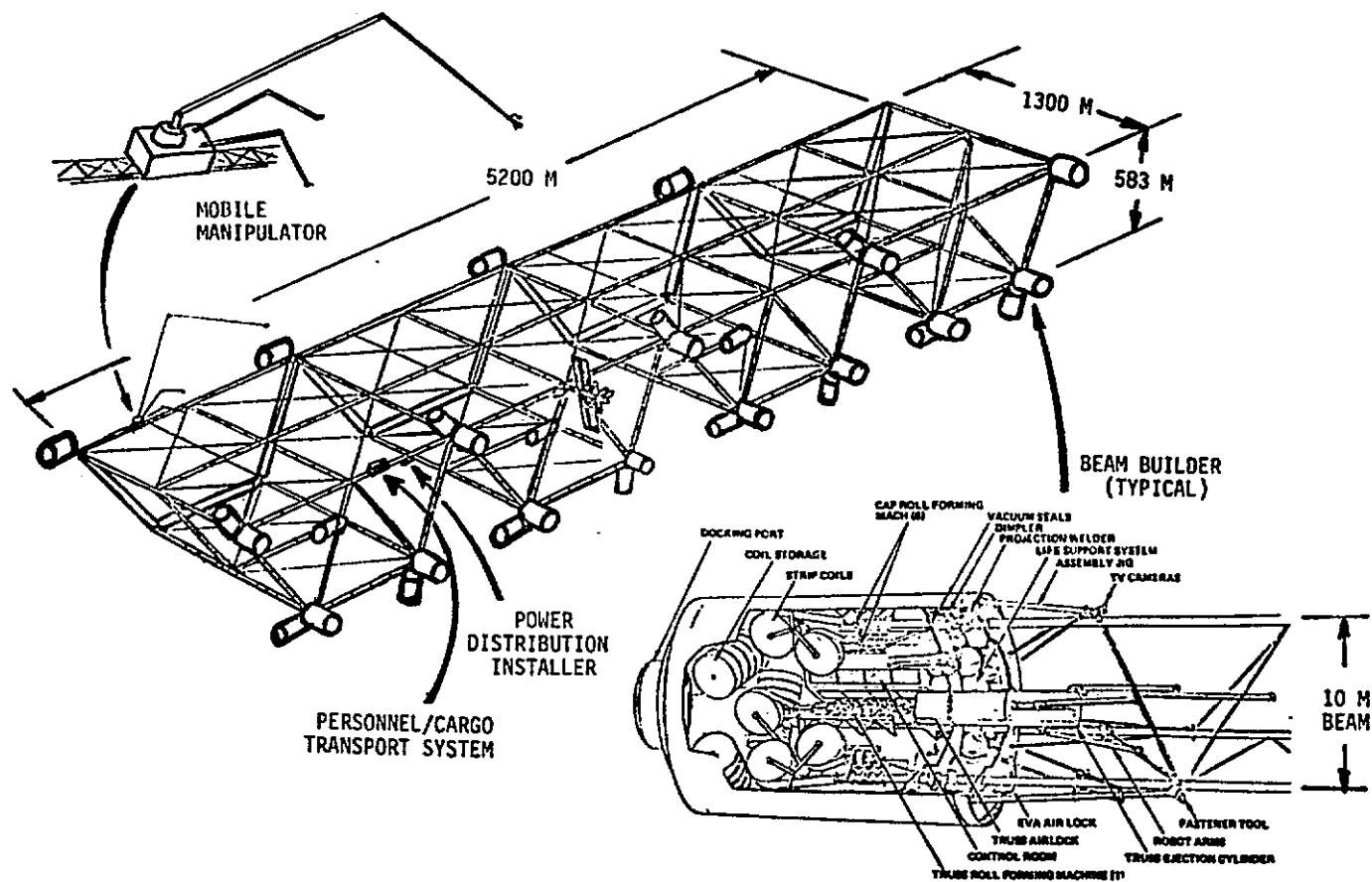


Figure 3.3.2-3 Truss Type SPS - Construction Facility Concept

Again centroidal node joints are assumed for joining the beams and the facility serves as the jig to aid in aligning the SECS trusses.

Simultaneous with SECS construction, the MPTSs are constructed by independent equipment and facilities at the outboard ends of the SECS structure (Figure 3.3.2-5).

Initially the MPTS extension structure at the facility end will be attached to the facility structure. When SECS construction is completed, this structure will be spliced to the SECS end-wall structure.

For the same reasons as for the C/C SPS, the truss SPS is also assumed constructed in GEO, with the facility constructed in LEO. Also, the construction facility can be separated and maneuvered to another site after the system is operational.

The functional analysis and construction schedule for the truss type SPS are presented in Table 3.3.2-1 and Figure 3.3.2-6, respectively. Approximately 60 different construction steps are identified, and over 50 specific equipment requirements were established. These equipment requirements may include logistics, construction equipment, or construction support equipment. Other miscellaneous requirements identified in the table may also encompass these categories of equipment. The maximum and minimum potential uses of man during construction and assembly are also described.

3.3.2.3 Truss Alternate - An alternate to the baseline truss construction method is to continuously extrude the longitudinal trusses and automatically install the lateral and transverse beams and cross-bracing tension cables. This method increases automation features, at the expense of complexity. The method of incremental assembly of the truss segments was selected as baseline since the time of assembling these segments and moving the facility would be relatively small compared to the time for fabricating the beams. The construction equipment required would be much simpler and more common to anticipated equipment required for other tasks, as well as for tasks in other large system concepts. The "continuous" construction method would have problems of accurate placement of side members while the structure is moving. Also, there would be problems of splicing in beams when the stock material must be resupplied in the fabricators.

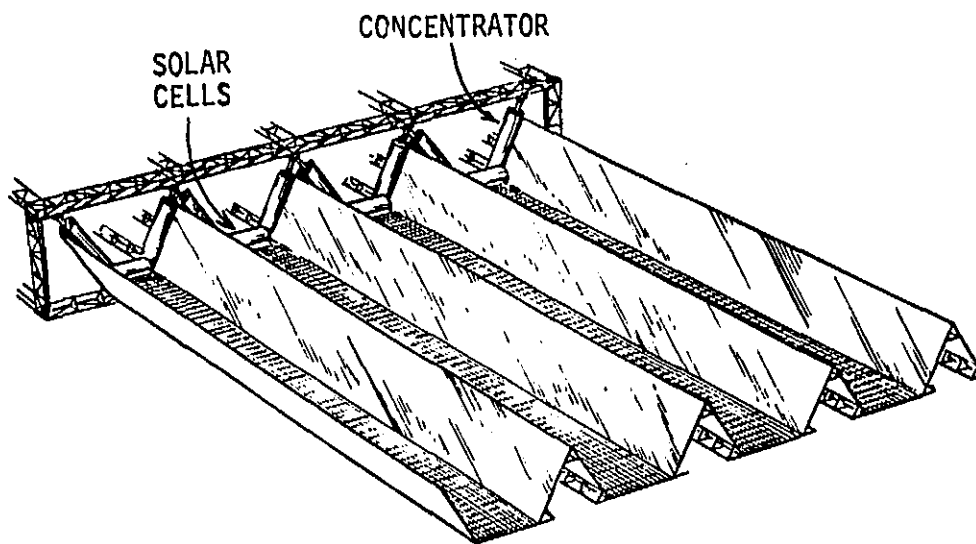


Figure 3.3.2-4 Truss Type SPS - SECS Installers

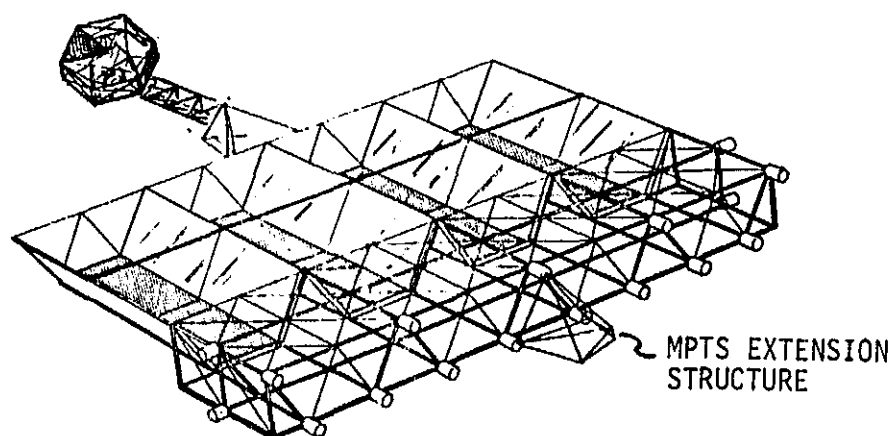


Figure 3.3.2-5 Truss Type SPS - Intermediate Construction Stage

Table 3.3.2-1 Truss Type SPS Construction - Functional Analysis

TASKS	TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
				MAXIMUM USE OF MAN	MINIMUM USE OF MAN
1.0 ASSEMBLE CONSTRUCTION FACILITIES (LEO)	One large facility will be constructed in LEO and boosted to GEO for subsequent construction of the SPS. The facility will include a large frame structure that is approximately 5200 meters long, 564 meters high, and 1300 meters wide (3.22 x 0.35 x 0.81 miles). The following construction equipment will be installed in the facility frame: • beam builders (32) • solar cell blanket installers (4) • concentrator installers (8) • tension cable installers (30) • power distribution harness installers (4) In addition, a separate manufacturing facility will be assembled, and maintained, in LEO for assembling SPS elements too large for direct launch from earth; e.g., MPIS subarrays, solar cell and concentrator rolls, etc.				
1.1 Build Facility Structure	The construction facility will be initiated with the launch of a construction base with equipment to manufacture triangular beams that are 10 meters (32.8 feet) on a side. This base will become the integration management and logistics facility (IMF + LF) during SPS construction.	• Construction base	• Docking provisions are required for subsequent resupply vehicles (materials, consumables, etc).		
1.1.1 Launch construction base with beam fabricator					
1.1.2 Install construction equipment	Construction equipment will be launched and installed on the forward base module. These will be used in taking fabricated beams and assembling the large facility frame. As portions of the facility are built, the SPS beam builders will be installed (step 1.2.1). These will then participate in accelerating the construction of the facility. Similarly, additional equipment will be installed and used in the facility assembly.				
1.1.3 Build beams	The same beam configuration used in the SPS construction will be used to assemble the facility frame. This enables using the SPS beam builders to build the facility.	• Capability to build beams that are 10 m (32.8 feet) on a side. The beam lengths are 650 m (2130 feet).			• Remote control and monitoring of fabrication. • Fabricator re-supply • Maintenance
1.1.4 Assemble facility frame	The fabricated beams will be assembled to form the facility frame. Construction equipment required to assemble the facility may be different than that to build the SPS.	• Capability to assemble the facility	• Facility beams will span distances up to ~. 650 m (2130 ft)	• Make connections between beams • Perform on-site	• Remote control of OCSE • Systems remote monitoring

Table 3.3.2-1 (Continued)

TASKS	TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
				MAXIMUM USE OF MAN	MINIMUM USE OF MAN
1.1.4 (Continued)			• Beam masses are up to ~837 kg (1840 lbs) • Beam joining methods are assumed to be the centroidal mode joint.	• monitoring to ensure alignments. • On-site operation of manipulators, like earth-operation of cranes • Maintenance	• Maintenance
1.2 Install Facility Equipment					
1.2.1 Launch and install beam builders (32)	As the facility frame is assembled, the SPS beam builders will be docked and installed into the facility.	• Beam builders will include manned habitats and resupply vehicle docking provisions	• Beam builders will build beams 10 m on a side and up to 650 m long	• Direct participation in installing builders	• Remote control of construction equipment
1.2.2 Launch and install solar cell blanket (4) and concentrator (8) installers	These equipment items will be docked and installed when the facility is completed.	• Capability to install installers in facility	• Installers span 650 m. • Solar cell rolls ~7 x 10⁶ kg total. • Solar concentrator rolls ~7 x 10⁵ kg total.	• Direct participation in installing builders.	• Remote control of construction equipment
1.2.3 Launch and install tension cable installers (30)	These installers will be unique to the SPS construction and therefore will also be installed after the facility is completed.	• Capability to install tension cable installers		• Direct participation in installing installers.	• Remote control of construction equipment
1.2.4 Launch and install power distribution harness installers	These installers will be installed after the facility is completed.	• Capability to install harness installers	• Weight and size TBD	• Direct participation in installing installers	• Remote control of construction equipment
1.2.5 Launch and install auxiliary equipment	Auxiliary equipment required to transfer the facility to geosynchronous orbit (GEO) will include propulsion modules, guidance and navigation systems, and attitude control. The same equipment will be used to stabilize the SPS/facility during the early construction phase.	• Capability to install auxiliary equipment	• TBD	• Direct participation in installing equipment	• Remote control of construction equipment

Table 3.3.2-1 (Continued)

TASKS	TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
				MAXIMUM USE OF MAN	MINIMUM USE OF MAN
1.3 Assemble Manufacturing Facility					
1.3.1 Launch facility modules	The manufacturing facility will be maintained in LEO and will manufacture/assemble SPS elements that are too large for direct earth launch. The facility will contain a habitat for crewmen, factory-type facility for assembly operations and/or manufacturing, material stowage area, docking provisions for resupply vehicles and propellant servicing facilities for orbit-to-orbit vehicles.	• Capability to assemble large habitable vehicle • Factory-type equipment for assembling/manufacturing specific SPS elements.	TBD	• Hands-on assembly of facility and SPS elements • Direct machine operation, resupply, and monitoring • Maintenance	• Remote control of factory operations from shirtsleeve environment • Monitoring of automated equipment • Machine resupply • Maintenance
1.3.2 Launch and install facility equipment					
1.3.3 Build facility					
2.0 BOOST ELEMENTS TO GEO					
2.1 Construction Facility	The construction facility will be transferred to GEO. The construction crews will follow to GEO in manned modules. These will dock to the beam builder facilities.	• Docking and crew transfer provisions			
2.2 Manned Modules					
2.3 Materials/Consumables	Materials and consumables will be boosted to GEO as required. These will dock at the logistics facility. From there, smaller transfer vehicles will distribute the commodities to the beam builder facilities.	• Cargo transfer vehicles • Docking and stowage provisions at the LF	• Cargo distribution distances up to 5200 meters (3.2 miles) round trip	• Fly with cargo vehicles to make the docking maneuvers • Direct participation in docking and unloading large cargo	• Remote control pilot of cargo vehicles • Remote control and/or monitoring of docking and unloading
2.4 Prefabricated Elements	Some SPS elements will be manufactured and/or assembled at the manufacturing facility (in LEO) and boosted in large packages to the SPS in GEO.	• Docking and stowage provisions at each facility			
2.5 Crew Exchanges	Construction crews will be exchanged periodically depending on the extent of manned participation and the length of time the crews can stay in GEO. These times will depend on the degree of protection from radiation.	• Manned orbit-transfer vehicle.			
3.0 CONSTRUCT SPS					
3.1 Construct SECS	All SECS construction will occur within the construction facility. The outboard end wall will be assembled. Then the longitudinal trusses will be constructed. These are constructed by assembling and adding on segments that are 650 meters on each leg. These segments are strengthened by tension cables. Lateral beams across the structure, top and bottom, are periodically installed. As the structure is				

Table 3.3.2-1 (Continued)

TASKS	TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
				MAXIMUM USE OF MAN	MINIMUM USE OF MAN
3.1 (Continued)	periodically moved out of the facility, solar cells, concentrators, and power distribution conductors are installed. The entire SECS structure is completed by adding the inboard end wall.				
3.1.1 Build outboard end wall	The SECS end wall will be assembled at the outboard side of the construction facility. The wall is a planar structure made up of 15 equilateral triangles, 65 meters on a side. The beams over the solar cell troughs will be fabricated and transferred for installation after clearing the facility.	• Capability to fabricate 10 x 650 m (33 x 2130 feet) beams and assemble wall	• Beams will span distances up to 650 meters • Beam masses are up to ~837 kg (1840 lbs) • Beam joining methods are assumed to be the centroidal node joint.	• Make connections between beams	• Remote control of construction equipment
3.1.2 Build longitudinal trusses	These trusses are fabricated in 13 beam builders. Alignment is achieved by fit to the facility jig.	• Capability to fabricate continuous beams (10 m on a side) up to 650 meters		• Perform on-site monitoring and resupply of beam fabricators • Maintenance	• Remote monitoring • Maintenance
3.1.3 Build and attach lateral trusses	The lateral trusses are fabricated by 7 beam builders (3 on the bottom and 4 at the top). The beams are attached at each intersection with longitudinal beams.	• Capability to fabricate beams 10 m on the sides and 1300 meters long (4 required)		• Same as 3.1.2 • Direct attachments between beams	• Same as 3.1.2 • Remote control of construction equipment
3.1.4 Build and attach side trusses	At each 650 meter increment on the longitudinal trusses, 8 side trusses are installed between the longitudinal beams. This will in effect form continuous columns (where the concentrators are installed) that are 650 meters on each side. Beam builders fabricate and extrude the trusses in near vicinity to the attached location.	• Capability to fabricate beams 10 m on the sides and 650 meters long. (8 required) • Capability to attach trusses.	• Same as 3.1.1	• Same as 3.1.3	• Same as 3.1.3
3.1.5 Attach diagonal tension cables	After each 650 meter increment of each column is assembled, diagonal tension cables will be attached across the square areas. Similarly cables are strung across the areas at the bottom of the solar cell trough.	• Capability to extend cable across area and attach/tension cables	• Cable span 920 meters (3000 feet)	• Direct attachment of cables	• Remote control of construction equipment

Table 3.3.2-1 (Continued)

TASKS	TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
				MAXIMUM USE OF MAN	MINIMUM USE OF MAN
3.1.6 Install concentrator material	As each 650 meter increment of SECS columns is moved outward, the concentrator material is transferred from the rollers onto the columns at 8 places. The material is electrically connected to the solar cell blankets as it is unrolled (step 3.1.7). The material is mechanically attached to the column.	• Capability to attach the material to the columns. • Capability to connect the material to the solar cell blanket	• Total concentrator material installed is 7.15×10^5 kg per location (1.57×10^6 lbs). Concentrator rolls will be resupplied periodically.	• Resupply of concentrator material. • Make initial and splicing connections.	• Remote control of replacement of rolls • Maintenance of rollers and attachment mechanisms.
3.1.7 Install solar cell blankets	As each 650 meter increment of SECS columns is moved outward, the solar cell blanket is transferred from the rollers and attached to the lower column trusses at 4 places. The blankets are attached electrically to the concentrators and mechanically to the trusses.	• Capability to attach the blankets to the column trusses. • Capability to attach the blankets to the concentrators	• Total solar cell material per location is 7.15×10^6 kg (15.7×10^6 lbs). Blanket rolls will be resupplied periodically.	• Resupply of solar cell blanket rolls • Make initial and splicing connections	• Remote control of replacement of rolls. • Maintenance of rollers and attachment mechanisms
3.1.8 Install power distribution system	The main power distribution mode is assumed through the aluminized concentrators. Additional conductors are needed to carry electrical power from each half of the SECS to the respective MPTSs. The conductor system for the outboard MPTS will be installed when the outboard end wall is completed. Connections to the concentrators will be made when the first sections of concentrators are installed. Similarly, the inboard conductor system is installed after the SECS structure is completed. Also, conductor splices will be made when concentrator material is resupplied. Appropriate switching equipment is required for circuit controls.	• Capability to install conductor cable systems in end wall and attach the conductors to the concentrators • Capability to electrically and mechanically splice concentrator material • Capability to install switching equipment	• Total length of conductor cables at each end wall is ~10,400 meters (34,100 feet) • Cable size is 12 cm dia. Mass is ~31 kg/m.	• Attachment of conductor cables to concentrators • Attachment of cables to structure • Attach switching equipment • Make connections at switching equipment • Make electrical and mechanical splices in concentrator material	• Remote control of equipment for installing conductor cables
3.1.9 Build inboard end wall	Similar to 3.1.1				
3.1.10 Attach MPTS to inboard end wall	When the inboard end wall is completed, the MPTS extension support structure will be spliced to the end wall by attaching end wall to portions of facility structure.			• Make structural attachments	• Remote control of construction equipment

Table 3.3.2-1 (Continued)

TASKS	TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
				MAXIMUM USE OF MAN	MINIMUM USE OF MAN
3.1.11 Install auxiliary equipment	All auxiliary equipment will be installed on the SECS within the construction facility, as applicable. Therefore, construction equipment may be compatible.				
3.1.11.1 Attitude control systems	MPD arc jet engines are assumed distributed about the edges of the SECS structure.	• Capability to install propulsion modules and associated control circuitry.	• Total weight 355,000 kg (includes 200,000 kg for 1 year of propellants) 66 engines assumed	• Direct installation and connections of systems	• Remote control of construction equipment
3.1.11.2 Instrumentation and communications systems	Systems include computer, data management, and TT&C.	• Capability to install systems	• Total weight ~4,000 kg		
3.2 Construct MPTS (2)	An MPTS at each end of the SECS structure converts DC power to microwave energy and transmits it to earth. Each antenna contains 7854 10 m x 10 m subarrays on a supporting structure. Each subarray is an integral unit containing microwave generators (klystrons or amplifiers), a slotted waveguide front face and control electronics. A rotary joint allows each antenna to be pointed as required toward the ground receiving antenna. Drive systems within this joint are controlled by a computer to correct pointing errors. Phase control, power distribution and pointing control systems are interconnected by electrical conductors or waveguides between subarrays or groups of subarrays for overall MPTS control. These systems (i.e., cables, computers) are mounted within the antenna structure behind the subarrays.		• MPTS = 1 km dia x 72 m depth (structure)		
3.2.1 Build MPTS support structure	The MPTS extension support structure connects the antenna itself with the main body of the SECS. This structure is made up of triangular beam sections. Interfacing structure between this support arm and the rotary joint frame is also attached (accommodates differences in geometry between rotary joint frame and support structure). Electrical conductors which carry the DC power from the SECS over the support structure are also installed at this time.	• Capability to fabricate and assemble support structure beams, interface structure • Capability to string and attach electrical conductors (~1 km in length)	• 1041 m length: 30 beams @ 100 m long, 4 @ 40 m, 25 @ 130 m (4.3 m triangular)	• Make connections between beams to assemble structure • Resupply beam fabricators • Perform on-site inspection and monitoring of beam joints, electrical	• Remote control of construction equipment • Remote systems monitoring • Resupply and manipulator operations from shirtsleeve environment.
3.2.1.1 Build extension structure					
3.2.1.2 Build rotary joint frame-to-support-structure interface					

Table 3.3.2-1 (Continued)

TASKS	TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
				MAXIMUM USE OF MAN	MINIMUM USE OF MAN
3.2.1-3.2.1.2 (Cont'd) 3.2.1.3 Install electrical conductors (SECS to joint interface)		Method to transfer material from fab facility outward along support structure		- conductor attachments - Manipulator operation	
3.2.2 Build rotary joint	The rotary joint contains separate azimuth and elevation joints with individual drive systems. The structure for the rotary joint is assembled in place, beginning at the interface to the extension structure (3.2.1.2). The joint drive systems are then installed within the structure at each joint; in addition, the brush/slip ring power transfer mechanism in the azimuth joint is also installed. The drive systems are interlocked to prevent rotation until the construction operations are completed.	- Joint structure fab/assy - Material transfer technique	Joint structure ~100 beams - 50 to 130 m long (4.3 m triangular)	- Direct fab and assy of joint structure - Installation of drive system, power transfer mechanism	Inspection of structure joints, drive/power transfer systems placement
3.2.2.1 Fab/assemble rotary joint structure					
3.2.2.2 Install drive system and power transfer mechanism in azimuth joint					
3.2.2.3 Install drive system in elevation joint					
3.2.2.4 Install electrical connectors between azimuth joint bus and brush/slip ring connectors	The power transfer system over the rotary joint is completed by installing wiring from the brush/slip ring connectors to a bus in the azimuth joint, from the azimuth joint bus to the rotary joint frame bus, and from the azimuth joint bus to the elevation joint bus. Finally, six support arms are built outward from the elevation joint structure. (These arms provide attachment points for the first concentric ring of the main MPTS substructure; see step 3.2.3.1)	Electrical conductor placement and attachment technique	- Electrical conductor length - azimuth bus to elevation bus ~150 m; others <20 m - Support arms - 2 @ 165 m long 50 @ 65 m, 4 @ 150 m (5.5 m triangular)	Wiring installation, connections made manually at each bus	Inspection of connectors, wiring
3.2.2.5 Install wiring from rotary joint frame to azimuth joint bus					
3.2.2.6 Install wiring from elevation joint bus to azimuth joint bus					
3.2.2.7 Build support arms (6)					

Table 3.3.2-1 (Continued)

TASKS	TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
				MAXIMUM USE OF MAN	MINIMUM USE OF MAN
3.2.3 Assemble MPTS substructure	Fabrication and assembly of the MPTS structure begins after the rotary joint is in place. The fabrication facility is part of the main SPS construction base (step 1.2). Assembly is accomplished at the antenna site, working from the center outward in concentric rings of structure. The first ring is a hexagon formed by six rectangular frames (65 m high x 130 m long); frame members are triangular beams 4.3 m on each side. Six other frames are used to form six equilateral triangles within the ring. The six outside frames are attached to the support arms constructed in step 3.2.2.7. Cables are attached to support each frame and to rigidize the hexagon formed by the frames. Secondary structures, fabricated and assembled at a separate location, are mounted on the top surface of the hexagon which constitutes the first concentric ring. These secondary structures are triangular (130 m on each side, 7 m in depth), and their internal structure forms a rectangular grid on the top surface of the antenna. These structures are delivered to the construction folded up and are deployed automatically (i.e., "popout") as required. They are attached to the main structure frames at three points. Six secondary structures are required for the first concentric ring of the antenna. Surface flatness is measured and adjusted as required. Once the first concentric ring is completed, assembly of the second concentric ring can begin. The same basic types of rectangular frame structure and supporting cables are utilized. Additional radial cables are used to tie the second ring to the first and, once the frame of the second ring is complete, circularize and rigidize the structure. As successive frames are attached to each other and initial cable attachments made to the first ring, the incomplete second ring must be supported and held in the proper position. Eighteen secondary structures are mounted to the top surface of the second concentric ring; these structures are similar to those utilized for the first	- Method to transfer material from fab facility over support structure to antenna - Capability to attach and apply tension to cables - Capability to assemble frames, connect frames together, connect first ring to ball joint attachment beams	- Triangular frame beams 4.3 m on a side by 65 m and 130 m long (12 required) 24 cables ~146 m long	- Direct control of frame assembly attachment and structure assembly - Direct control of cable tensioning	Remote monitoring of automatic manipulator process; inspection of joints
3.2.3.1 Build first concentric ring					
3.2.3.2 Install secondary structures		- Transport method for secondary structures - Manipulator attachment techniques - Alignment measurement and adjustment techniques	- Six secondary structures - Dimensions (folded): TBD ~1200 kg (2640 lbs) each	- Deployment of secondary structure, attachment of secondary structure to main frames using manipulators - Direct control of flatness adjustments	Monitoring of secondary structure deployment; monitoring of attachment procedure; inspection of surface flatness
3.2.3.3 Build second concentric ring		- Same as 3.2.3.1 and 2, plus: support arms to hold second ring frames in place while mating frame is attached and radial cables attached. - Same as 3.2.3.3	- Triangular frames 130 m x 65 m (12 required) - Frame cables (24 required) ~146 m long. - Radial cables (36 required) 12 @ 150 m ea 24 @ 175 m ea 18 secondary structures	- Same as 3.2.3 plus installation of radial tension cables and control of support arms for second ring frame - On-site alignment between rings and adjustment of flatness	Monitoring and inspection of assembly

Table 3.3.2-1 (Continued)

TASKS	TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
				MAXIMUM USE OF MAN	MINIMUM USE OF MAN
3.2.3.3 (Continued)	ring in that they "popout" for deployment and are attached at three points, but the shapes vary to accommodate ring geometry. Additional rings are built outward, as each successive ring is completed, of 18 and 24 sides each, to achieve a 1 km diameter.		• 3rd ring: 30 sec structures, 36 frame cables, 60 radial cables • 4th ring: 42 sec structures, 18 frames & 184 radial cables		
3.2.4 Install subarrays	Subarrays (10 m x 10 m ea) are nonstructural elements which contain the power conversion and transmission equipment. Each antenna contains 7854 subarrays, which are mounted on the top surface of the secondary structure.	• Transfer method for subarrays from fab facility to secondary structure surface. • Attachment technique	• 7854 10 m x 10 m subarrays. 156 to 140 kg (343 to 528 lbs) each	• Attachment of individual subarrays to secondary structure • On-site inspection, monitoring	• Remote inspection
3.2.4.1 Fabricate subarrays					
3.2.4.2 Mount subarrays on antenna secondary structure	The subarrays are fabricated in a separate facility (MF-1) and transported to the antenna construction site. Each subarray contains microwave generators (klystrons or amplitrans), a waveguide system for phase control, power distribution system wiring and an electronics package, all mounted beneath the slotted waveguides front face through which the microwave energy is transmitted. The subarrays are attached to the secondary structure at three points. They can be mounted as each concentric ring is completed or immediately after each secondary structure is installed (before other secondary structures are in place), or subarray installation can be accomplished after the entire antenna structure is complete.				
3.2.5 Install phase control system	Since each microwave generator acts as a separate radio transmitter, phase information must be available to each generator so that system efficiencies are optimized. This is accomplished via an RF signal sent from the ground to the MPTS, which is transferred through the subarrays to each microwave generator.	• Electrical conductor connections between subarrays (waveguide attach or wire connectors).	• Electrical conductor length in 10 m increments	• On-site placement and attachment of conductors between electronics packages.	• Remote inspection of connections
3.2.5.1 Interconnect electronics packages between subarrays	For phase control, the subarrays are interconnected in series with 8 to 16 subarrays per group. The subarrays in each group are connected electrically (waveguides or wires). This interconnection is accomplished through the electronics packages and can be done at any time after the subarrays in any concentric ring are mounted on the secondary structure or after all subarrays are mounted in the MPTS.				

Table 3.3.2-1 (Continued)

TASKS	TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
				MAXIMUM USE OF MAN	MINIMUM USE OF MAN
3.2.5.2 Install RF lines from reference subarrays to subarray groups	In order to bring the phase control signal sent from the ground and received at the center of the antenna to the subarray groups (700) over the MPTS surface, RF lines (700 transmission lines) are routed from the antenna center to the first subarray in each subarray group. These lines can be attached at the antenna center as soon as the first concentric circle (with subarrays) is complete and the connections can be completed as soon as the outer subarray groups are placed. Alternately, the transmission lines can be attached as a single task after all subarrays have been mounted in the MPTS.	RF transmission line attachment mechanism	~700 RF transmission lines, max length = 500 m	Placement and attachment of cables to subarrays (both ends)	Attachment of cables at subarray end, after initial attachment of cables at antenna center as part of the subarray group fabrication.
3.2.6 Install power distribution system	The microwave energy transmitted to earth from the MPTS is that energy collected by the SECS, transferred to the MPTS as DC power over the rotary joint and distributed to each microwave generator. Each subarray, as mounted in the secondary structure (step 3.2.3.4), contains the wiring for power distribution from the electronics package within the subarray to each microwave generator.	- Transfer technique to carry switch gears to antenna - Electrical conductor attachment method	16 switch gears 2000 kg (4400 lbs) each. - Conductor length-switch gears to ball joint bus 4 @ ~600 m; 4 @ ~500 m; 4 @ ~400 m; 4 @ ~300 m. - Conductor lengths-switch gear to dist pts (main lateral path): 4 @ 500 m; 4 @ 400 m; 4 @ 300 m; 4 @ 200 m, plus ~1000 wires avg length 100 m. - Intersubarray wiring 10 m increments max length 30 m	- Installation and attachment of switch gears - Installation and attachment of wiring from switch gears to rotary joint bus. - Installation and attachment of wiring to distribution points - Installation and attachment of wiring between subarrays	Monitoring/inspection of wiring connections, switch gear attachments
3.2.6.1 Install switch gears					
3.2.6.2 Attach electrical conductors from rotary joint bus to switch gears	Sixteen switch gears are required, mounted in two rows of eight along the antenna axis, as the interface between the power from the SECS and the individual subarrays. These switch gears are attached to the antenna structure, within the secondary structure.				
3.2.6.3 Install electrical conductors from switch gears to distribution points	Electrical conductors are then attached from the switch gears to the rotary joint (elevation axis) bus. These lines would be placed along the antenna structure radially to the antenna center, then axially (elevation joint axis) to the rotary joint bus.				
3.2.6.4 Install electrical conductors at distribution points between subarrays	Electrical conductors are also placed laterally from each switch gear to distribution points in each antenna quadrant. Each switch gear services between 100 and 400 distribution points depending upon its location on the axis. Depending upon the distance from the antenna center, these distribution points transfer power to one, two or four subarrays. Wiring between subarrays at such distribution points must also be placed.				

Table 3.3.2-1 (Concluded)

TASKS	TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
				MAXIMUM USE OF MAN	MINIMUM USE OF MAN
3.2.7 Install pointing control system	A control signal sent from the ground to the MPTS is used to measure pointing errors, and a computer is used to command the rotary joint drive systems to correct such errors. The computer is mounted near the center of the antenna within the structure. This computer is connected to seven reference subarrays used to measure pointing errors, and to the drive systems via electrical wiring.	• Technique to mount computer in structure • Wire installation, connection	• Computer size TBD • Wiring lengths subarrays to computer: 3 @ 75 m; 2 @ 200 m; 2 @ 300 m. • Computer to rotary joint: 40 m to elevation joint; 140 m to azimuth joint	• On-site placement of computer wiring	• Remote inspection of electrical connections
3.2.7.1 Mount pointing control computer in antenna structure					
3.2.7.2 Install wiring between reference subarrays and computer					
3.2.7.3 Install wiring between computer and rotary joint drive systems					
4.0 ACTIVATE SPS	The following tasks are required to complete the construction activities and make the SPS operational.				
4.1 Activate Attitude Control System	The attitude control systems will be activated and checked out.	• Systems C&D area in IMF		• Systems monitoring and control	
4.2 Orient SPS to POP and Solar Orientation	The SPS will be maneuvered to the desired orientation.			• System monitoring and control	
4.3 Unlock MPTS Joints Activate Computer and Point MPTSs	The MPTS joints will be unlocked (see 3.2.2). The computer will be activated. The MPTSs will be pointed and the automatic steering control system will be activated.			• Systems monitoring and control	
4.4 Check Out Subsystems	All SPS subsystems will be checked out before and after activating the SPS power systems.				
4.5 Detach and Remove Construction Facilities	After the SPS is operational and verifications are complete, the construction facility is removed and maneuvered to another construction site. This will require some structure disassembly and separate removal of installers.	• Capability to disassemble structure and remove installers • Transfer vehicles		• Direct disassembly tasks	• Remote control of OCSE

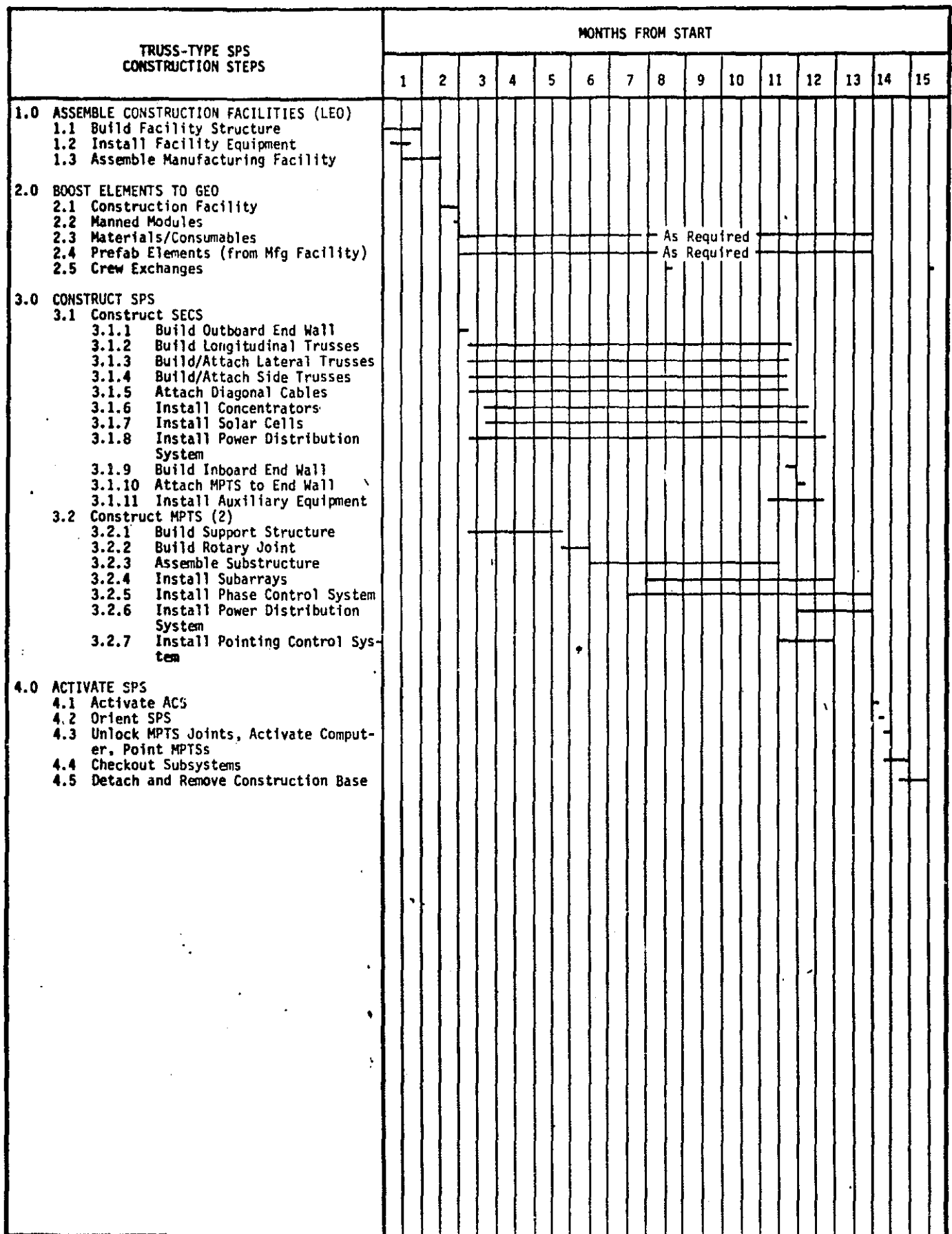


Figure 3.3.2-6 Truss Type SPS Construction Timelines

3.3.3 Brayton-cycle Thermal Engine SPS

3.3.3.1 Overview - The Boeing concept of the Brayton-cycle thermal (BT) engine SPS is presented in Figure 3.3.3-1. The total system is comprised of four power modules and a MPTS. (Ongoing studies may derive different system sizes and may incorporate a second MPTS.) At each power module, solar radiation is concentrated by steerable facet reflectors (17,000 in each module) into a power conversion system (PCS) cavity absorber. Piping inside the cavity delivers heated helium to drive turbogenerators which generate three-phase AC electrical power. The electrical energy is delivered through the three-element spinal truss to rotary transformer at the MPTS interface. Here the electrical energy is converted to DC for driving the microwave generators. Waste heat is rejected from each PCS via a liquid metal (NaK) system and large halo radiators.

3.3.3.2 Construction Activities - The baseline construction methods assumed (partially derived from Boeing concepts) for the BT SPS includes constructing the power conversion system (PCS) inside a hexagonal construction jig structure, as shown in Figure 3.3.3-2. The cavity absorber shell is assembled from pre-fabricated panel sections. When the shell is sufficiently assembled, structure is installed around the cavity opening as a base for installing the solar concentrator (SC) structural struts (see Figure 3.3.3-3). The SC is assembled using mobile beam builder facilities while the remainder of the PCS is assembled.

The mobile beam builders are assumed capable of fabricating two beams simultaneously and contain a manipulator system for installing lateral beams and tension cables (see Figure 3.3.3-4). These SC facilities will also install structural framework to form the SC bowl, overlay this framework with popout secondary structures, and install reflector facets into steering mechanisms previously installed in the structure (see Figure 3.3.3-5).

The PCS construction facility contains six manipulators for installing the PCS elements and two long cranes (≈ 900 m) for installing the massive radiator segments and the spinal truss structure.

Simultaneous with the PCS construction, a MPTS is constructed at a separate site. When the four power modules and the MPTS are constructed, the MPTS is temporarily attached to the bottom of one of the modules. Ion/chemical propulsion units are attached (Figure 3.3.3-6) and the four modules are boosted to GEO.

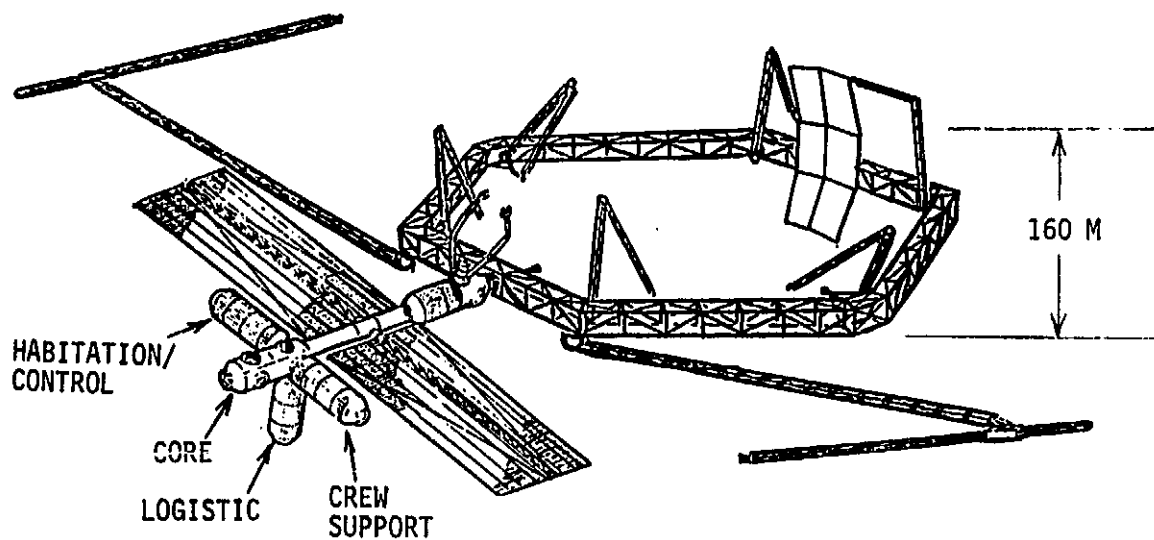


Figure 3.3.3-2 Thermal Engine SPS - Construction Facility Concept

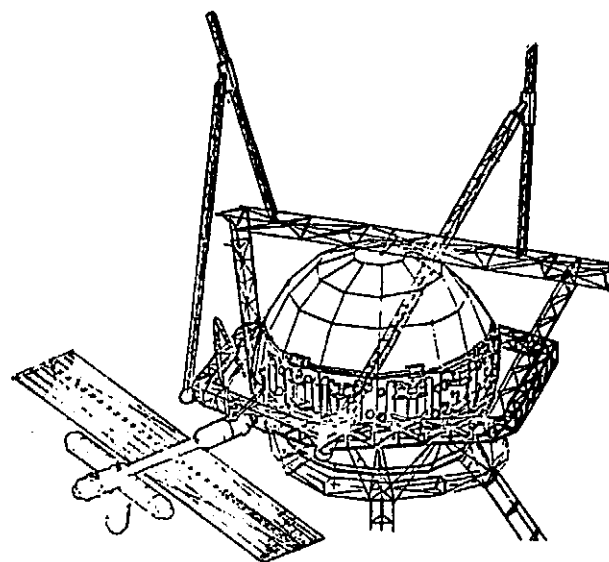


Figure 3.3.3-3 Thermal Engine SPS - SC Base Structure

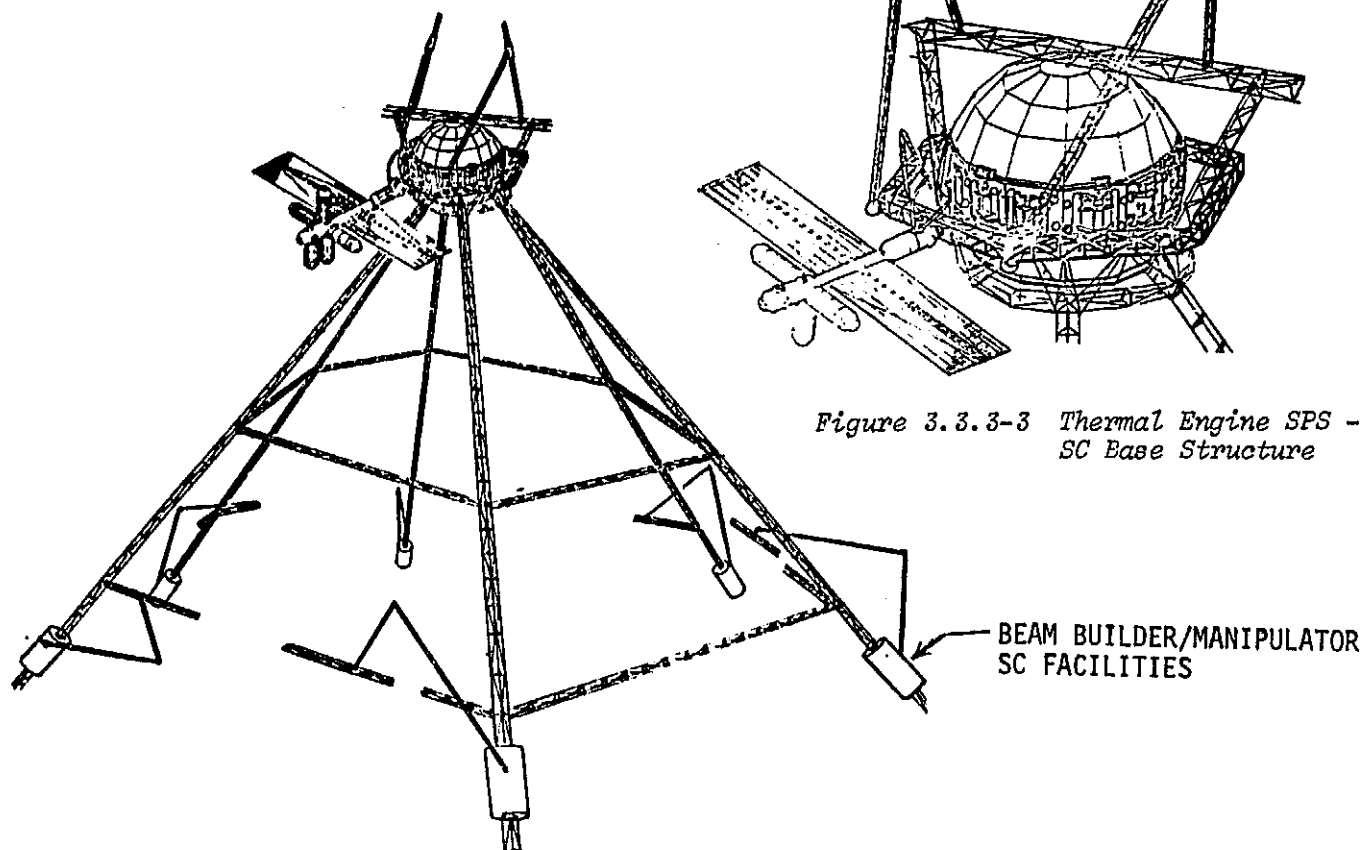


Figure 3.3.3-4 Thermal Engine SPS - SC Construction Facilities

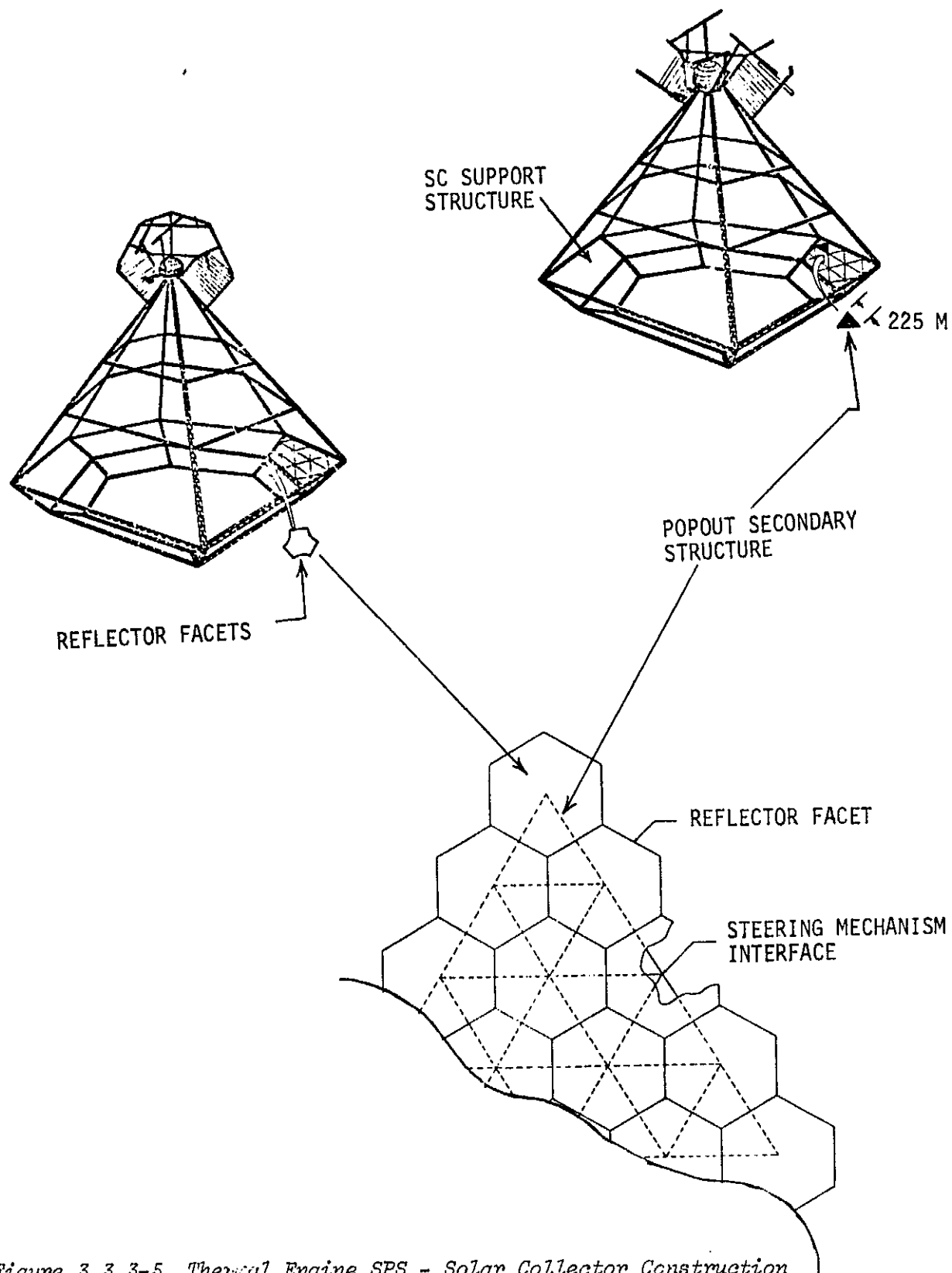


Figure 3.3.3-5 Thermal Engine SPS - Solar Collector Construction

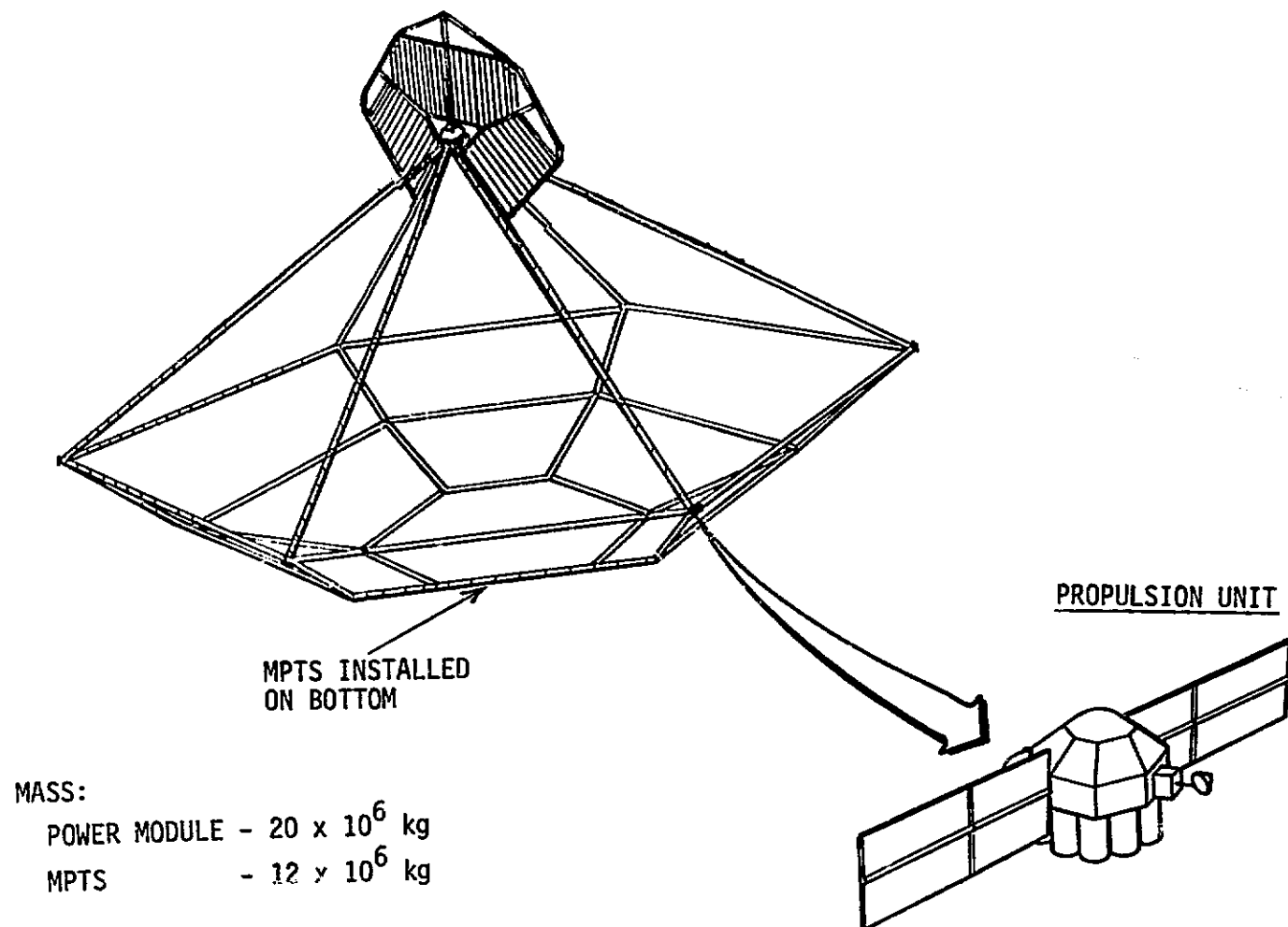


Figure 3.3.3-6 Thermal Engine SPS - GEO Transfer Configuration

Table 3.3.3-1 Thermal Engine SPS Construction - Functional Analysis

TASKS	TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
				MAXIMUM USE OF MAN	MINIMUM USE OF MAN
1.0 ASSEMBLE CONSTRUCTION FACILITIES (LEO)	Each of the SPS modules will be constructed in LEO, boosted to GEO, and joined in GEO to form the total SPS. Initially four construction facilities (CF-1 through -4) will be assembled in LEO. These will independently assemble the four power conversion systems (PCS). Six additional beam-builder facilities for each module (CF-5 through -28) will be assembled in LEO and attached to the PCSs. These will then construct the solar concentrator (SC) assembly. Simultaneously, CF-29 will be assembled in LEO and used for constructing the MPTS. A manufacturing facility (MF-1) will be assembled and maintained in LEO for assembling SPS elements too large for direct launch from earth; e.g., MPTS subarrays, popout SC secondary structures, radiators, etc.		CF-1 thru CF-4 will provide the integration management (IMF) and logistics facilities (LF). All construction facilities will include manned modules. Stationkeeping systems are provided in all facilities.		
1.1 Construct CF-1 thru CF-4 for PCS Assembly	Construction bases are launched with the capability to manufacture square beams 8 meters on a side. OCSE (manipulators) are launched and installed on each facility. The OCSE will take the fabricated beams and assemble the hexagon structure. The OCSE manipulators will be installed at the interior side of the apexes as the hexagon structure is assembled. PCS stanchions are also installed at these points.	- Capability to fabricate 8 x 125 meter (26 x 410 feet) square beams. - Capability to assemble facility. Manipulators to be installed are: Cavity construction - 6 required, ~110 meters each; Radiator construction - 2 required, ~700 meters each.	- Facility beams will span 86 m. Beam masses are up to ~215 kg (473 lbs). - Docking provisions on the manned facility are needed for OCSE and subsequent resupply vehicles. - Beam joining methods are assumed to be welded butt joints.	- Make the connections between beams. - Resupply beam fabricators. - Perform on-site monitoring of beams to ensure joint integrity and alignments. - On-site operation of OCSE manipulators. - Maintenance.	- Remote control of OCSE. - Systems remote monitoring. - Fabricator resupply from shirtsleeve environment. - Maintenance.
1.1.1 Launch construction base with beam/fabricator (4)					
1.1.2 Install construction equipment					
1.1.3 Fabricate facility beams					
1.1.4 Assemble facility (4)					
1.2 Construct CF-5 thru CF-28 for SC Assembly	These facilities will be launched and assembled when the PCS construction has proceeded to the point where the SC support spokes are ready to be assembled. These facilities are envisioned as capable of building beams out both ends and containing manipulators for installing transverse SC beams and cables.	- Capability to fabricate triangular beams 10 x 338 m (33 x 1100 feet). Beams to 1600 m long are required between the SC spokes. - Capability to install beams spanning 1600 m.	Beam mass ~1.3 kg/meter		

Table 3.3.3-1 (Continued)

TASKS	TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
				MAXIMUM USE OF MAN	MINIMUM USE OF MAN
1.2 (Continued)		• Capability to install cables spanning 2050 m. • Manipulators with 150 m reach.			
1.3 Construct CF-29 for MPTS Assembly	This facility will be self-supporting. Stationkeeping systems, logistics facilities, and manned modules will be included. This facility will assemble the 130 x 65 m frames (with cross-cables) used in constructing the MPTS polygon structure. The frame trusses are triangular at 4.3 m on a side. The facility is envisioned as 30 x 70 x 150 m. Fabricators, OCSE, and jigs are provided in 3 bays for concurrent manufacture of 3 frames at a time. The same facility will provide support to the OCSE for assembly of the MPTS, including attachment structure, substructure, secondary structure, subarrays, and operating equipment.	• Capability to fabricate 4.3 x 150 m (14 x 500 ft) beams and assemble these into the required facility frame.	• Facility beams will span up to 150 meters. • Beam mass is up to ~54 kg (119 lbs). • Docking provisions are required for subsequent resupply vehicles. • Self-sustaining systems: ACS, GN&C, power, etc.	Same as 1.1	Same as 1.1
1.4 Construct MF-1	The manufacturing facility will be maintained in LEO, near to the SPS construction sites. This facility will manufacture/assemble SPS elements that are too large for direct earth launch. The facility will contain a crewman habitat, factory-type facility for assembly operations, material stowage area, docking provisions for resupply vehicles, and propellant servicing provisions for orbit-to-orbit vehicles.	• Capability to assemble large habitable vehicle. • Factory-type equipment for fabricating/assembling specific SPS elements.	• Subarrays = 200 kg. Material package = TBD kg.	• Hands-on assembly of facility and SPS elements. • Direct machine operation, resupply and monitoring. • Maintenance.	• Remote control of factory operations from shirtsleeve environment. • Monitoring of automated equipment. • Machine resupply. • Maintenance.
1.4.1 Launch facility modules					
1.4.2 Assemble facilities					
1.4.3 Launch and install facility equipment					
2.0 CONSTRUCT SPS					
2.1 Construct Individual Modules (4)					
2.1.1 Construct PCS (4)					
2.1.1.1 Assemble cavity absorber shell	The PCS construction starts by assembling the cavity absorber shell. The surface of the shell is made up of series of flat facets. Around the center is a belt of 32 facets, where the bulk of the Brayton cycle machinery will be installed. These facets are alternately 20 m (65.6 ft) square and 20 x 9 m	• Capability to install facet sections on CF stanchions and install remaining facets	• Cavity sphere size 150 m (492 ft) dia. • Mass of 20 x 29 m section with gas piping	• Direct involvement in joining structure facets. • On-site operation of manipulators	• Remote control of OCSE. • Maintenance.

Table 3.3.3-1 (Continued)

TASKS	TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
				MAXIMUM USE OF MAN	MINIMUM USE OF MAN
2.1.1.1 (Continued)	(65.6 x 29.5 ft). The majority of the remainder of the facets are 20 m square with smaller, tapered, flat panels in between to complete the sphere. It is probable that several of the facets could be assembled into larger elements at MF-1 and transferred to the PCS sites.	Manipulator lengths required are about 110 m.	- and insulation ~53,000 kg each (116,600 lbs). 98 sections.	Maintenance of OCSE.	
2.1.1.2 Install fluid piping	It is assumed that the gas (helium) heat exchanger piping inside the absorber cavity will be part of the structure facets. Connections will be made between sections as the absorber sphere is assembled. It is assumed that the gas piping inlet and outlet for each section can be on the exterior of the sphere for ease of assembly. At installation of the waste heat radiators, liquid metal (NaK) piping is installed between the PCS and radiators.	- Capability to make gas piping connections (exterior access assumed). - Capability to install and connect liquid metal piping.	- Sizes TBD. - Sizes TBD.	- Direct joining of gas piping. - Direct installation of piping.	- Remote control of OCSE. - Remote control of OCSE.
2.1.1.3 Install turbo-generator sets	Sixteen 300 MW turbogenerator (TG) sets will be installed around the periphery of each PCS sphere. Each set will be preassembled in MF-1 prior to transfer to the PCS site.	Capability to transfer and install TG sets on cavity structure.	Mass of each TG set ~236,400 kg (520,000 lbs)	- Direct joining of connections. - On-site operations of manipulators.	Remote control of OCSE.
2.1.1.4 Install Radiators	A halo radiator assembly will be installed on each SPS module. These will be installed on the +X structure spoke after the SC structure assembly has progressed sufficiently. Since the mass of each radiator assembly will be ~6 x 10 ⁶ kg, it is assumed each radiator will be assembled from several segments. This will then require on-site mechanical and fluid piping connections.	Capability to transfer and install radiator segments and make piping connections.	Assume 12 radiator segments at ~500,000 kg (10⁶ lbs) with dimensions of ~180 x 730 m.	- Direct installation and connection activities. - On-site operation of manipulators.	Remote control of OCSE.
2.1.1.5 Leak check and charge fluid systems	As each fluid system is installed, leak checks will be performed to verify system integrity. If leakage is present, methods must be employed to isolate leak location and seal the leak. As part of activating the system, the fluid systems will be charged. The helium system presents no problem and can be remotely activated by opening the accumulator supply valve. The NaK system presents some problems. The NaK metal must be in liquid form to flow into the system and the system must be operating to maintain the liquid form. The NaK charging therefore will be in GEO as part of activating the SPS.	- Leak check fluid systems. Method TBD. - Locate point of leakage. Method TBD. - NaK loading system to melt the metal compound and charge the PCS system.	~4.8 x 10⁶ kg NaK in each radiator.	- Manual leak check methods. - Fly-around leak detection routine and evaluation. - Leak repair. - Connection of NaK loading system and on-site operation	- Remote monitoring of leak check method. - Leak detection and evaluation - Leak repair. - Connection of NaK loading system and remote operation

Table 3.3.3-1 (Continued)

TASKS	TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
				MAXIMUM USE OF MAN	MINIMUM USE OF MAN
2.1.2 Construct Solar Concentrators (SC)					
2.1.2.1 Install SC support base structures	The cavity absorber shell will have truss pads incorporated at appropriate spots for anchoring the SC support struts. Preassembled base structures will be installed on these pads using the PCS construction facilities. These structures will provide docking for the SC construction facilities.	CF-1 thru CF-4 facilities.		Direct connection of base structure.	Remote control of OCSE.
2.1.2.2 Dock CF-5 thru CF-28 to support strut base	These construction facilities will have fly-around capability and contain beam fabricators and manipulator systems. Each facility will dock to the SC support strut bases constructed in 2.1.2.1. A beam will be partially fabricated and attached to the support strut base.	Capability to fabricate SC triangular beams and attach beam to base while docked or stationkeeping.	- Control of docking maneuvers. - Direct connections of beam to base.	Remote control of OCSE.	
2.1.2.3 Build SC support struts and cross-trusses	Each SC construction facility will continue to build the beam strut. This will in effect move the facilities away from the PCS. Simultaneously, a beam will be built out the other end of each facility. At the appropriate time, this second beam will be installed between support struts.	Capability to fabricate and install beams 10 m on a side and up to 1600 m (1 mile) long	Beam mass up to 1560 kg (3430 lbs).	Make connections of cross-beams.	- Remote control of OCSE. - Material resupply. - Maintenance.
2.1.2.4 Install tension cables	Tension cables will be periodically installed to stabilize the long support struts. Cable layout is TBD.	Capability to install tension cables over spans up to 2775 m (9100 feet).		- Transfer cables across span. - Install cable ends and tension cables.	- Remote control of OCSE. - Material resupply. - Maintenance.
2.1.2.5 Build reflector framework	When the SC construction facilities have built the struts to the desired lengths, beams will be taken from the other end of the beam fabricators and, by use of the manipulators, placed in positions to start building a framework for the bowl of the SC. The construction facilities will move themselves, by use of the manipulators, to other places on the bowl framework as required to continue building the framework. When the equilateral-triangle structures are completed, "popout" secondary structures will be transferred to the sites and installed. (This concept was devised to present a possible SC assembly method. The bowl framework would have to be re-worked to achieve the equilateral layout. Existing Boeing data is incomplete in this area.)	- Same construction facility capability as in 2.1.2.3. - Manipulator capability to move construction facility.	- Popout secondary structure weight ~5000 kg (11,000 lbs). ~762 secondary structures installed each module. - Facility mass TBD.	Direct connection of beam ends.	- Remote control of OCSE. - Material resupply. - Maintenance.

Table 3.3.3-1 (Continued)

TASKS	TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS ^c (Mass, Distance, Size, Etc)	MAN'S ROLE	
				MAXIMUM USE OF MAN	MINIMUM USE OF MAN
2.1.2.6 Install reflector facets	Preassembled reflector facets are installed at each top joint of the "popout" secondary structure. Each facet is individually steered by a 2-axis drive assembly. The drive assembly is mechanically attached at the structure joints.	- Transfer facets to installation sites. - Install facet drive assembly at secondary structure joints.	~17,000 facets installed each module. - Mass ~ 65 kg (143 lbs) per facet.	Make mechanical connection.	Remote control of OCSE.
2.1.2.7 Install reflector control systems	Each facet contains a sensor and circuitry to automatically maintain focusing on the cavity absorber. However, remote control of the facet steering is required to permit defocusing the facets in the event of PCS contingencies that require removing radiation into the cavity. Circuitry for power to the drive assemblies and control signals is required for each facet. Circuitry will be preassembled in the secondary structures and will be installed on the primary beams as they are constructed. All circuitry must be connected as the assembly operations occur.	Capability to make electrical circuitry connections.	- Connections at ~17,000 facets on each module. - Connections at ~30 primary structure joints	Make electrical connections.	Remote control of OCSE.
2.1.3 Construct/install power distribution system	Power is transferred from the turbogenerators up the primary bus trusses to the spinal truss. The spinal truss carries power to the end module, down the SC strut near the MPTS, and to the rotary transformer joint (see 2.2). The generated power is 3Ø. Each longitudinal member of the transfer beams carries a phase. Cross-members are insulated from the long elements.	Unique beam fabricators to build power conducting beams. (These beams could be special built in MF-1.)			
2.1.3.1 Install primary power bus trusses	The primary power bus trusses are installed on the PCS-to-SC interface structure.	Facility manipulators adequate.	Beam lengths ~150 m. Mass ~146 kg.	- Make beam connections. - Direct operation of manipulators.	Remote control of OCSE.
2.1.3.2 Install spinal truss	The spinal truss is installed between the top ends of the primary power bus trusses. This spinal truss will eventually be extended when all SPS modules are joined in GEO.	Facility manipulators adequate.	Beam lengths ~340 m. Mass ~330 kg.	- Make beam connections. - Direct operation of manipulators.	Remote control of OCSE.
2.1.3.3 Connect PCS primary power bus bars	Bus bars are installed on the PCS to carry power from the turbogenerators and are connected to the primary bus trusses.	Capability to install power bus bars and connections with primary bus trusses.		Make bus bar installations and connections.	Remote control of OCSE.

Table 3.3.3-1 (Continued)

TASKS	TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
				MAXIMUM USE OF MAN	MINIMUM USE OF MAN
2.1.4 Prepare SPS elements for transfer to GEO	The separate SPS modules will be transferred to GEO for final assembly. The following tasks are required to prepare the SPS elements for this orbit transfer.				
2.1.4.1 Install auxiliary systems	Those systems will be installed that will monitor orbital parameters and integrate orbit-transfer functions for control of the propulsion modules. The same systems may be used for controlling the steering of the SPS when operational or additional systems may be installed. Permanent operational ACS will be installed.	• Use PCS construction facilities.	• Attitude control ~400,000 kg each module.	• Direct connection of auxiliary systems.	• Remote control of OCSE.
2.1.4.2 Install MPTS on SC	The MPTS will be installed on the bottom of one of the SC modules for transfer to GEO.	• Capability to transfer MPTS to SC provided by CF-29. • Capability to install MPTS on SC. • Use SC construction facilities.	• MPTS mass ~12x10⁶ kg.	• Make mechanical connections between MPTS and SC.	• Control docking maneuvers. • Remote control of OCSE.
2.1.4.3 Install orbit transfer system	Three orbit transfer vehicles will be installed on each SPS module. These vehicles will be remotely maneuvered to the docking points and connected using on-site equipment.	• Capability to connect OTV to SPS module. • Use SC construction facilities.	• OTV mass - TBD	• Make mechanical and electrical connections.	• Remote control of OCSE.
2.1.4.4 Remove construction facilities	Those construction facilities will be removed (fly-away) that are not needed in the GEO operations. CF-1 thru CF-4 and 2 of each of the SC facilities will be needed. These will be secured on the SPSS. CF-29 will be required for MPTS maneuvers.	• CF fly-away capabilities.	• CF-1 will become the single IMF in GEO		
2.2 Construct MPTS	The thermal type SPS concept utilizes one MPTS to transmit to earth all energy collected from the 4 modules. MPTS construction and assembly includes building the antenna and extension structure and attaching the rotary transformer assembly (RTA) in LEO. This entire assembly is constructed independently (from PCS and SC) and then transported to GEO (on a SPS module) where it is attached to the SC assembly. The antenna contains 7854 10 m x 10 m subarrays on a supporting structure. Each subarray is an integral unit containing microwave generators (klystrons or amplifiers), a slotted waveguide front face and		1 km dia antenna x 72 m depth (structure) NOTE: The use of 1 MPTS (of 1 km dia) to transmit total energy output of the PCS to earth conflicts with NASA concepts, which use 2 antennas for each SPS.		

Table 3.3.3-1 (Continued)

TASKS		TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
					MAXIMUM USE OF MAN	MINIMUM USE OF MAN
2.2 (Continued)		control electronics. Phase control, power distribution and pointing control systems are interconnected by electrical conductors or waveguides between subarrays or groups of subarrays for overall MPTS control. These systems are mounted within the antenna structure behind the subarrays. The extension structure physically connects the antenna to the RTA at the end of the SC, and allows 360° of rotation of the antenna about the long axis of the SC. The rotary transformer assembly (RTA) is the actual joint which allows the antenna to rotate for pointing toward earth. The RTA is attached to the extension structure (in LEO) and the main SC frame (in GEO); and includes power conversion and transfer equipment to the antenna systems. Antenna pointing control methods are TBD.				
2.2.1 Assemble MPTS substructure		CF-29 is utilized to construct the MPTS. Since this task is accomplished independently from other SPS construction, CF-29 must be capable of stabilizing itself and the MPTS, at least during early construction phases. This facility will construct the main antenna structure and the extension structure (including support attachments to the MPTS).	• Capability to fabricate 4.3 m x 150 m beams, build attachment arms. • Docking facilities for resupply. • Method to transfer material from fab facility over support structure to antenna. • Capability to attach and apply tension to cables. • Capability to assemble frames connect frames together.	• Triangular frame beams - 4.3 m on a side by 65 m and 130 m long (12 required). • 24 frame cables ~146 m long.	• Make connections between beams to assemble structure. • Direct control of frame assembly attachment and structure assembly. • Direct control of cable tensioning.	• Remote control of construction equipment. • Remote systems monitoring. • Remote monitoring of automatic manipulator process; inspection of joints.
2.2.1.1 Build first concentric ring		Assembly is accomplished working from CF-29 (at what would be the antenna center) outward in concentric rings of structure. The first ring is a hexagon formed by six rectangular frames (65 m high x 130 m long). Frame members are triangular beams 4.3 m on each side. Six other frames are used to form six equilateral triangles within the ring.				

Table 3.3.3-1 (Continued)

TASKS	TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
				MAXIMUM USE OF MAN	MINIMUM USE OF MAN
2.2.1.2 Install secondary structures	Secondary structures, fabricated and assembled at a separate location, are mounted on the top surface of the hexagon which constitutes the first concentric ring. These secondary structures are triangular (130 m on each side, 7 m in depth) and their internal structure forms a rectangular grid on the top surface of the antenna. These structures are attached at 3 points to the main structure frames, and are delivered to the construction site folded up, to be deployed as required for attachment. Deployment is automatic (i.e., popout). Six secondary structures are required for the first concentric ring of the antenna. Surface flatness is measured and adjusted as required.	• Transport method for secondary structures. • Manipulator, attachment techniques. • Alignment measurement and adjustment technique.	• Six secondary structures. Dimensions (folded): TBD • ~1200 kg (2640 lbs each).	• Deployment of secondary structure, attachment of secondary structure to main frames using manipulators. • Direct control of flatness adjustments.	• Monitoring of secondary structure deployment; monitoring of attachment procedure; inspection of surface flatness.
2.2.1.3 Build second concentric ring	Once the first concentric ring is completed, assembly of the second concentric ring can begin. The same basic types of rectangular frame structure and supporting cables are utilized. Additional radial cables are used to tie the second ring to the first and once the frame of the second ring is complete, circularize and rigidize the structure. As successive frames are attached to each other, and initial cable attachments made to the first ring, the incomplete second ring must be supported and held in the proper position. Eighteen secondary structures are mounted to the top surface of the second concentric ring; these structures are similar to those utilized for the first ring in that they "popout" for deployment and are attached at three points, but the shapes vary to accommodate ring geometry.	• Same as 2.2.1.1 and 2.2.1.2 • Support arms to hold second ring frames in place while mating frame and radial cables attached	• 18 secondary structures (2nd ring) • 3rd ring (18 frames); 30 sec structures; 36 frame cables @ 146 m ea; 48 radial cables @ 175 m ea; 12 radial cables @ 150 m ea. • 4th ring (24 frames); 42 sec structures; 48 frame cables @ 146 m; 72 radial cables @ 175 m; 12 radial cables @ 150 m.	• Same as 2.2.3 plus installation of radial tension cables and control of support arms for second ring frames. • On-site alignment between rings and adjustment of flatness.	• Monitoring and inspection of assembly.
2.2.1.4 Build third and fourth concentric rings	Additional rings are built outward, as each successive ring is completed, of 18 and 24 sides each, to achieve 1 km diameter.	• Same as 2.2.1.3			
2.2.2 Install subarrays	Subarrays (10 m x 10 m ea) are nonstructural elements which contain the power conversion and transmission equipment. Each antenna contains 7854 subarrays, which are mounted on the top surface of the secondary structure.	• Transfer method for subarrays from fab facility to secondary structure surface. • Attachment technique.	• 7854 10 m x 10 m subarrays. 156 to 240 kg (343 to 528 lbs) per subarray.	• Attachment of individual subarrays to secondary structure. • On-site inspection, monitoring.	• Remote inspection.
2.2.2.1 Fabricate subarrays					
2.2.2.2 Mount subarrays on antenna secondary structure	The subarrays are fabricated in a separate facility (MF-1) and transported to the antenna construction site. Each subarray contains microwave generators (klystrons or amplifiers), a waveguide system for phase control, power distribution system wiring and an electronics package, all mounted beneath the				

Table 3.3.3-1 (Continued)

TASKS	TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
				MAXIMUM USE OF MAN	MINIMUM USE OF MAN
2.2.2 - 2.2.2.2 (Cont'd)	slotted waveguide front face through which the microwave energy is transmitted. The subarrays are attached to the secondary structure at three points. They can be mounted as each concentric ring is completed or immediately after each secondary structure is installed (before other secondary structures are in place), or subarray installation can be accomplished after the entire antenna structure is complete.				
2.2.3 Install phase control system	Since each microwave generator acts as a separate radio transmitter, phase information must be available to each generator so that system efficiencies are optimized. This is accomplished via an RF signal sent from the ground to the MPTS, which is transferred through the subarrays to each microwave generator. For phase control, the subarrays are interconnected in series, with 8 to 16 subarrays per group. The subarrays in each group are connected electrically (waveguides or wires). This interconnection is accomplished through the electronics packages, and can be done at any time after the subarrays in any concentric ring are mounted on the secondary structure or after all subarrays are mounted in the MPTS.	Electrical conductor connection between subarrays (waveguides attach or wire connectors).	Electrical conductor length in 10 m increments.	On-site placement and attachment of conductors between electronics packages.	Remote inspection of connections.
2.2.3.1 Interconnect electronics packages between subarrays					
2.2.3.2 Install RF lines from reference subarrays to subarray groups	In order to bring the phase control signal sent from the ground and received at the center of the antenna to the subarray groups (~700) over the MPTS surface, RF lines (~700 transmission lines) are routed from the antenna center to the first subarray in each subarray group. These lines can be attached at the antenna center as soon as the first concentric circle (with subarrays) is complete, and the connections can be completed as soon as the outer subarray groups are placed. Alternately, the transmission lines can be attached as a single task after all subarrays have been mounted in the MPTS.	RF transmission line attachment mechanism.	~700 RF transmission lines, max length = 500 m.	Placement and attachment of lines to subarrays (both sides).	Attachment of lines at subarray end, after initial attachment of lines as part of that subarray group fabrication.
2.2.4 Install power distribution system	The microwave energy transmitted to earth from the RTA is that energy collected by the SECS, transferred to the MPTS as DC power over the joint and distributed to each microwave generator. Each subarray, as mounted in the secondary structure (step 2.2.2.2), contains the wiring for power distribution from the electronics package within the	- Transfer technique to carry switch gears to antenna. - Electrical conductor attachment method.	16 switch gears 2000 kg (4400 lbs) each. - Conductor length switch gears to ball joint bus: 4	- Installation and attachment of switch gears. - Installation and attachment of wiring	Monitoring/inspection of wiring connections, switch gear attachments.
2.2.4.1 Install switch gears					

Table 3.3.3-1 (Continued)

TASKS	TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
				MAXIMUM USE OF MAN	MINIMUM USE OF MAN
2.2.4.2 Attach electrical conductors from RTA bus to switch gears	subarray to each microwave generator. Sixteen switch gears are required, mounted in two rows of eight along the antenna axis, as the interface between the power from the SECS and the individual subarrays. These switch gears are attached to the antenna structure within the secondary structure.		0~600 m; 4 @ ~500 m; 4 @ ~400 m; 4 @ ~300 m.	from switch gears to ball joint bus.	
2.2.4.3 Install electrical conductors from switch gears to distribution points	Electrical conductors are then attached from the switch gears to the RTA bus (2.2.2.3). These lines would be placed along the antenna structure radially to the antenna center, then axially (elevation joint axis) to the RTA joint bus.		• Conductor length switch gears to distribution points (main lateral path): 4 @ 500 m; 4 @ 400 m; 4 @ 300 m; 4 @ 200 m, plus ~1000 wires average length 100 m.	• Installation and attachment of wiring to distribution points.	
2.2.4.4 Install electrical conductors at distribution points between subarrays	Electrical conductors are also placed laterally from each switch gear to distribution points in each antenna quadrant. Each switch gear services between 100 and 400 distribution points depending upon its location on the axis. Depending upon the distance from the antenna center, these distribution points transfer power to one, two, or four subarrays. Wiring between subarrays at such distribution points must also be placed.		• Intersubarray wiring 10 m increments, max length 30 m.	• Installation and attachment of wiring between subarrays.	
2.2.5 Install pointing control system	TBD				
2.2.6 Build joint support arms	Support arms (beams) are attached to the edge of the outer (4th) MPTS concentric ring substructure and the extension structure is built to house the power conversion equipment (step 2.2.8.3 below) and provide an attachment point for the RTA.	• Capability to transfer material over extension structure to support arms truss work.	• Extension structure: 4 @ ~30 m; 4 @ 20 m (4.3 m triangular). Support arms: 4 @ 65 m long, 4 @ 25 m; 10 @ 30 m (4.3 m triangular)	• Resupply beam fabricators	• Resupply and manipulator operations from shirtsleeve environment.
2.2.7 Build extension structure		• Stabilization system		• Perform on-site inspection and monitoring of beam joints, electrical conductor attachments.	
2.2.8 Install rotary transformer assembly (RTA)	The RTA structure is delivered to CF-29 as a unit and attached (via latitude actuators) to the extension structure. The RTA assembly (including the latitude actuators) is locked to prevent inadvertent rotation during MPTS construction.	• Manipulators to put RTA assembly in place.	• RTA ~20 m dia	• Manipulator operation.	• Remote operation, monitoring.
2.2.8.1 Attach RTA to extension structure		• Locate and attach power conversion equipment.		• Electrical conductor attachment.	
2.2.8.2 Install power conversion/filter unit	Power conversion equipment is installed within the extension structure and electrical conductors are installed from that equipment through the extension structure to the MPTS interface. Finally, the vernier linear actuator halves are attached between	• Electrical conductor attachment.			

Table 3.3.3-1 (Continued)

TASKS	TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
				MAXIMUM USE OF MAN	MINIMUM USE OF MAN
2.2.8.3 Install electrical conductors from power conversion unit to MPTS interface	the RTA and the extension structure.				
2.2.8.4 Attach halves of vernier linear actuators					
3.0 BOOST ELEMENTS TO GEO					
3.1 SPS Modules	The construction crews would return to earth while the SPS modules are transferred to GEO. The transfer will be controlled from the ground. Minimum crews will be launched to GEO to arrive when the SPS modules arrive.		• SPS module mass ~20 x 10⁶ kg. • Module with MPTS mass ~32 x 10⁶ kg.		
3.2 Construction Facilities					
3.3 Manned Modules					
4.0 ASSEMBLE SPS	The modules will be maneuvered together by use of the OTVs. The SC facilities will fabricate connector beams and will connect the SC edges. Methods are TBD.	• Use CF equipment.		• Attachment of beams. • On-site control of equipment.	• Remote control of OCSE.
4.1 Join Modules					
4.1.1 Maneuver modules together					
4.1.2 Attach modules at SC edges	Additional spinal trusses must be installed between the four PCSs. These are the power carrying trusses that would be unique assemblies. These trusses would be fabricated from facilities carried to GEO or would be preassembled in MF-1 and transferred to GEO. Because of the large span between PCSs, maneuverable vehicles are envisioned for installing these trusses.	• Maneuverable vehicles for installing spinal trusses.	• Span between PCSs ~4500 m (~2.8 miles).	• Attachment of spinal truss. • Direct control of vehicles.	• Remote control of vehicles and OCSE.
4.1.3 Install trusses between PCSs					
4.2 Install MPTS					
4.2.1 Maneuver MPTS to SC edge	After all modules are in GEO, the MPTS will be undocked from the SC and maneuvered to the edge of the SC. One of the SC construction facilities will be used to make the connection of the MPTS support structure to the SC.	• CF-29 maneuvering capability. • SC construction facility adequate for MPTS installation.		• Make mechanical connections between MPTS and SC. • Direct operation of OCSE.	• Remote control of OCSE.
4.2.2 Attach MPTS support structure to SC structure					

Table 3.3.3-1 (Concluded)

TASKS		TASK DISCUSSION	EQUIPMENT REQUIREMENTS	MISCELLANEOUS REQUIREMENTS (Mass, Distance, Size, Etc)	MAN'S ROLE	
					MAXIMUM USE OF MAN	MINIMUM USE OF MAN
4.2.3 Connect power distribution system		When the MPTS is connected, electrical connections will be made between the power transfer SC strut and the rotary transformer joint (see 2.2).	• SC construction facility usage.		• Make electrical connections. • Direct operation of OCSE.	
5.0 ACTIVATE SPS		The following tasks are required to complete the construction activities and make the SPS operational.				
5.1 Activate Attitude Control Systems		The attitude control systems will be activated and checked out.	• Systems C&D area in IMF.		• Systems monitoring and control.	
5.2 Maneuver SPS to Solar Orientation		The SPS will be maneuvered to the desired orientation			• Systems monitoring and control.	
5.3 Unlock MPTS Joint Activate and Point MPTS		The MPTS joint will be unlocked (see 2.2.2). The MPTS will be pointed and the automatic steering control system will be activated.			• Systems monitoring and control.	
5.4 Check Out Subsystems		All SPS subsystems will be checked out before and after activating the SPS power systems. Charge the N ₂ K system immediately before focusing the facets activating the PCS.			• Systems monitoring and control. • Operation of N ₂ K loading system.	• Connect N ₂ K loading system.
5.5 Detach and Remove Construction Facilities		After the SPS is operational and verifications are complete, the construction facility is removed and maneuvered to another construction site. This will require some structure disassembly and separate removal of installers.	• Capability to disassemble structure and remove installers. • Transfer vehicles.		• Direct disassembly tasks.	• Remote control of OCSE.

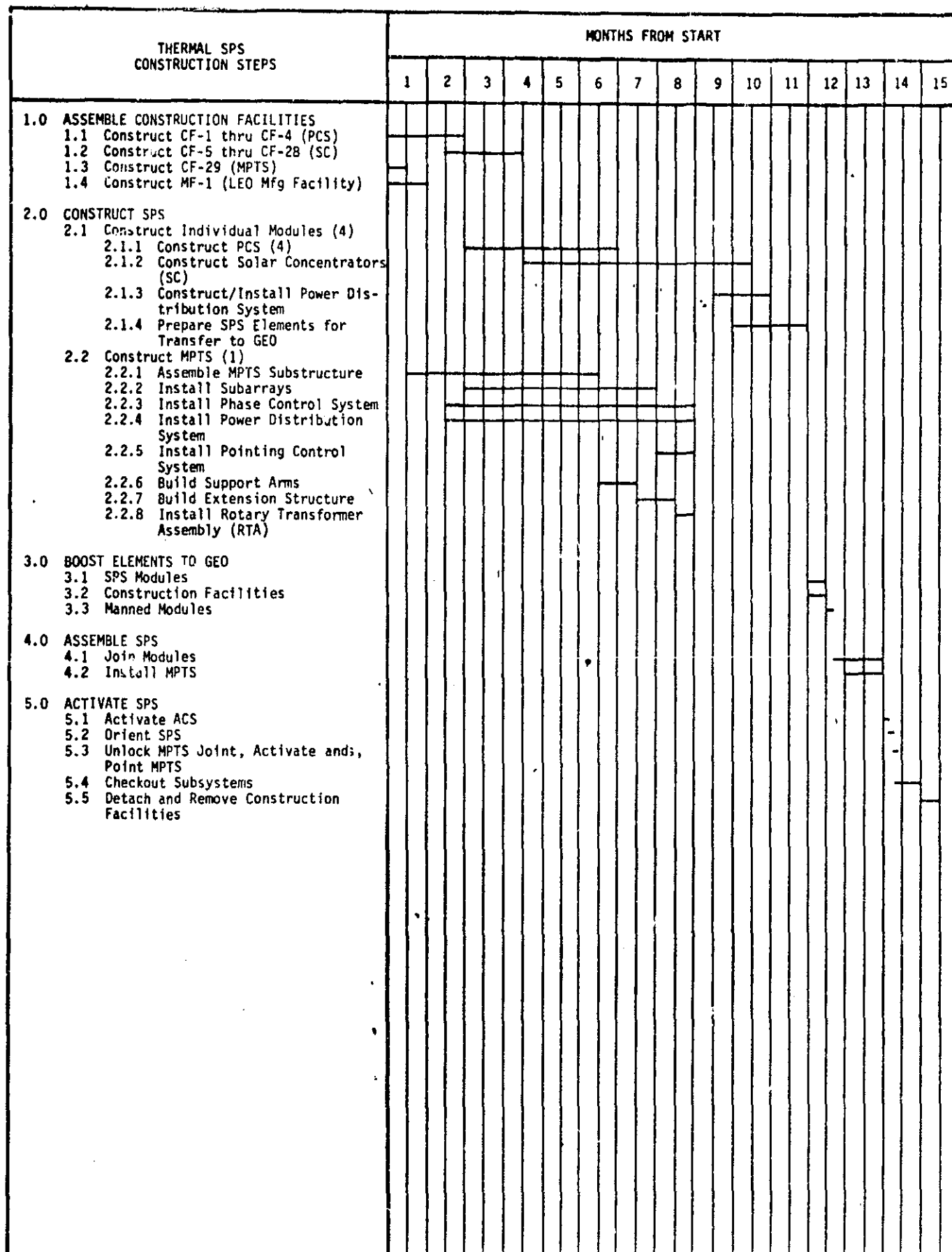


Figure 3.3.3-7 Boeing Thermal SPS Construction Timelines

There the modules and MPTS are maneuvered together and joined at the SC edges. The construction of the spinal truss between the PCSs is completed and the power transmission system is connected. The heat transfer systems are charge simultaneously with focusing the solar radiation into the PCSs and activating the generator systems. The construction facilities are left in place as an aid in performing maintenance during the operational phase.

The functional analysis and construction schedule for the Boeing thermal SPS are shown in Table 3.3.3-1 and Figure 3.3.3-7, respectively. Approximately 60 different construction steps are identified, and over 65 specific equipment requirements were established. These equipment requirements may include logistics, construction equipment, or construction support equipment. Other miscellaneous requirements identified in the table may also encompass these categories of equipment. The maximum and minimum potential uses of man during construction and assembly are also described.

3.3.3.3 BT Option - Option A to the baseline construction method assumes the SC bowl structures are installed using a long boom, with traveling manipulators and cargo transporters, similar to the concept shown in Figure 3.3.3-8. The baseline strut beam builders would be located at the SC periphery and would continue to fabricate SC bowl structure beams. The boom assembly would transfer the beams and install them. This concept eliminates the need (in the baseline) for the beam builders to "walk along" the SC structure during assembly. The boom pivot area could also serve as a logistics supply area for preassembled secondary structures and reflector facets. This eliminates the long transfer distances from the PCS facility. This SC facility would be left in place for operational maintenance activities, such as removing deteriorated reflector facet layers.

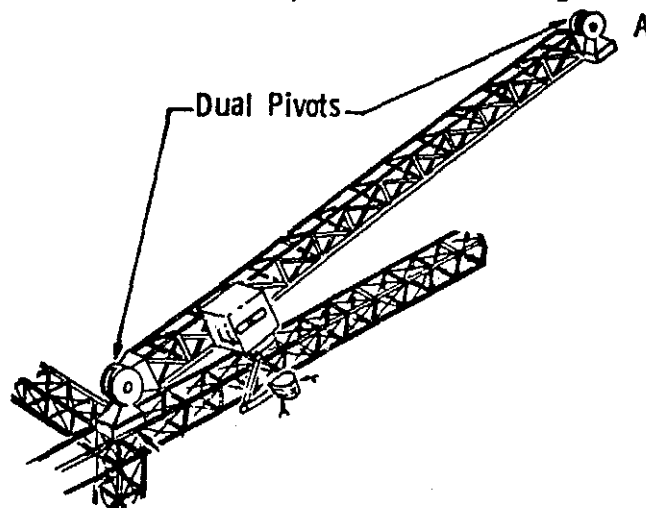


Figure 3.3.3-8 Long Boom Use in BT SPS

3.3.4 Microwave Power Transmission System (MPTS)

3.3.4.1 Overview - The microwave power transmission system (MPTS) accepts DC electrical power from the collector portion of the SPS, converts this power to microwave energy and beams the energy to an earth receiver (rectenna). For the purposes of the study, a single MPTS configuration was applied to the three SPS baseline concepts. For each concept, however, a different MPTS joint (physical connection between the collector portion of the SPS and the MPTS) configuration was assumed.

Except for the possible utilization of any one of three joint concepts (ball joint, rotary joint or rotary transformer assembly) and for differences in scheduling dictated by the overall SPS construction scheme, the MPTS assemblies are the same for any of the baselined SPS concepts. Each MPTS (two required for the column/cable and truss type, one for the thermal SPS) is a 1-km diameter antenna which is built outward from its center in concentric rings of substructure.

Figure 3.3.4-1 shows the major structural components of the MPTS.

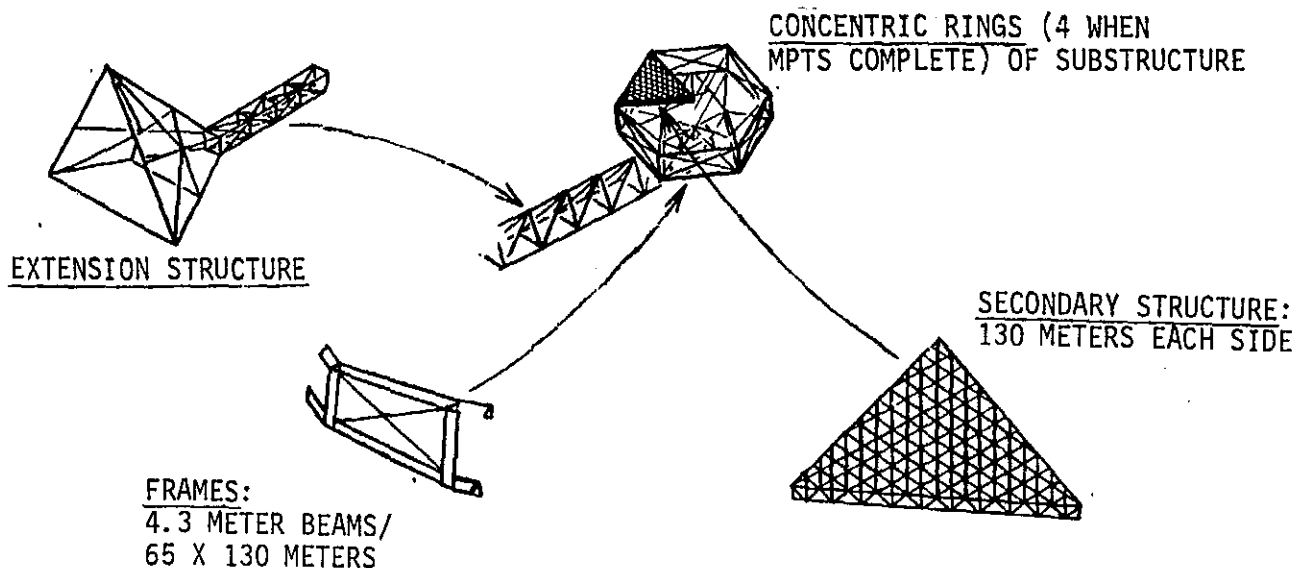


Figure 3.3.4-1 MPTS Major Structural Components

Additional subsystems which provide for power distribution, phase control and antenna pointing are mounted within the main structure. The joint between the MPTS and the main body (collector) of the SPS allows the antenna to rotate a full 360° about one axis and to pivot 15° in the plane of another axis. This

rotation is required to insure that the antenna can achieve proper pointing to the earth-based rectenna.

Figure 3.3.4-2 shows the sequence of major construction activities. The construction equipment used to assemble the rings and place the secondary structures/subarrays would be mounted either at the end of the extension structure near the joint (working from the bottom of the antenna) or at the top center of the first ring.

3.3.4.2 MPTS Construction Activities - Construction of the MPTS is accomplished concurrently with the main body of the SPS. For the column cable and truss concepts, the MPTS is assembled while physically attached (via the extension structure) to the main SPS; for the thermal engine SPS, the MPTS is assembled apart from the concentrator/collector modules and attached to the edge of the modules after assembly is completed.

The physical interface between the MPTS and the solar collector is an extension structure, which is long enough to provide clearance between the main SPS structure and the antenna for pointing. The joint, which accomplishes the two-axes pointing, is mounted at the end of the extension structure. Additional structural elements (support arms) attach the joint to the main MPTS substructure.

The functional analysis and construction schedule for the MPTS are incorporated into the analyses made for each SPS concept (see Tables 3.3.1-1, 3.3.2-1 and 3.3.3-1 and Figures 3.3.1-7, 3.3.2-6, and 3.3.3-7).

a. MPTS Structure - The main substructure of the MPTS is made up of four concentric rings of framework; each frame is 130 meters long by 65 meters high, and the rings contain 6, 12, 18, and 24 frames around their respective circumferences. Successive rings are connected via radial cables which provide support by holding the frame structures in hoop compression. Secondary structures, of roughly triangular shape 130 meters on a side and 7 meters high, are mounted to the top of the frames between concentric rings. These structures are folded into rectilinear packages for delivery to the construction site and "pop out" for deployment. Figures 3.3.4-3 and 3.3.4-4 show the main components of the MPTS structure in detail.

b. MPTS Subsystems - The major subsystems of the MPTS are power distribution, phase control and pointing control. In each case, the primary interfaces are contained in the subarrays which are the prime active components of the

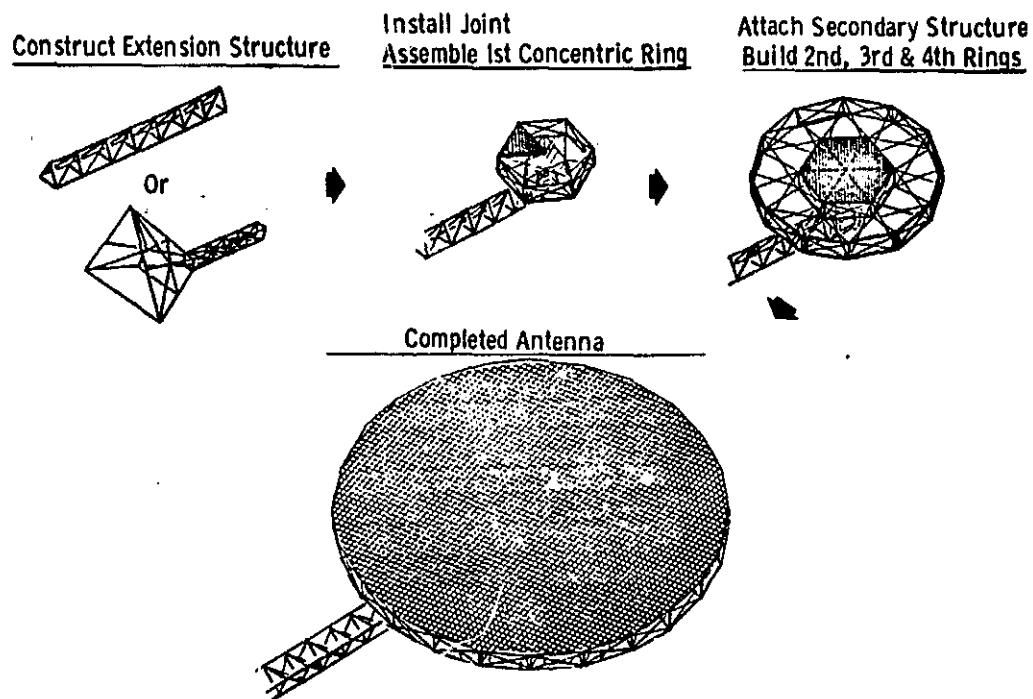


Figure 3.3.4-2 MPTS Construction

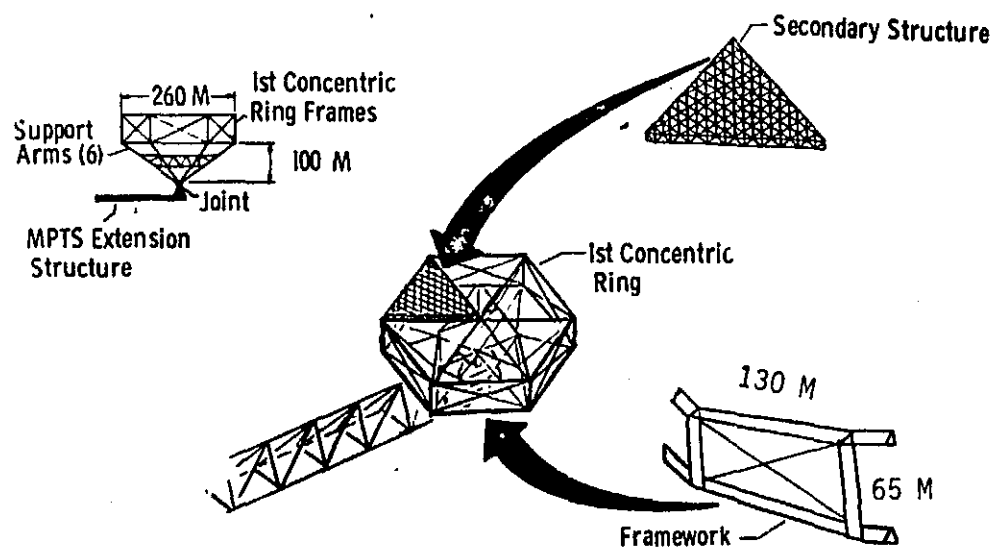


Figure 3.3.4-3 MPTS Construction - Extension Structure/Joint/1st Concentric Ring

MPTS. Each subarray acts as a microwave transmitter to earth. These subarrays (7854) are mounted individually to the top surface of the secondary structures (see Figure 3.3.4-5) and contain from 10 to 40 microwave generators (klystrons) each. Electronics mounted on each subarray interface with the power distribution, phase control and pointing control systems as required.

Figure 3.3.4-6 shows the MPTS power distribution system, as seen from the back surface of the secondary structure. Power conductors from the joint are routed to 16 switch gears mounted along the antenna diameter in the secondary structure. Additional conductors carry the power from each switch gear to distribution points in subarray groups. Wiring internal to the subarrays then takes the power to each microwave generator (for transmission to earth).

The phase control system is depicted in Figure 3.3.4-7. The phase differences of the microwave signals transmitted to earth from each klystron are minimized by inputting a reference signal to each klystron. This signal is received from the ground at the center of the MPTS and transmitted to subarray groups via RF lines. Additional lines carry this signal to the individual subarrays in the group. Wiring internal to each subarray then takes the signal to each microwave generator.

Antenna pointing is controlled by a computer (mounted in the secondary structure) and achieved via the drive system associated with the joint. Pointing error signals from the ground are received at seven reference subarrays and transmitted to the computer for comparison. Pointing commands are then sent to the drive system. Figure 3.3.4-8 shows the MPTS pointing control system.

c. Joints - A different joint concept was applied to each of the three SPS concepts studied, although these concepts are interchangeable in that any could be utilized with any of the SPS concepts. For the purpose of this study, the ball joint concept was employed with the column/cable SPS, the rotary joint with the truss-type SPS, and the rotary transformer assembly (RTA) with the thermal SPS (refer to Figures 3.3.4-9, 3.3.4-10, and 3.3.4-11).

The ball joint (column/cable SPS) is small enough to be delivered to the MPTS construction site as a unit, where it is attached to the extension structure. The ball joint (7.5 meter dia.) is not a load bearing attachment but acts only as the point of rotation for the antenna assembly, and as the path for transfer of electrical power between the solar collectors and the

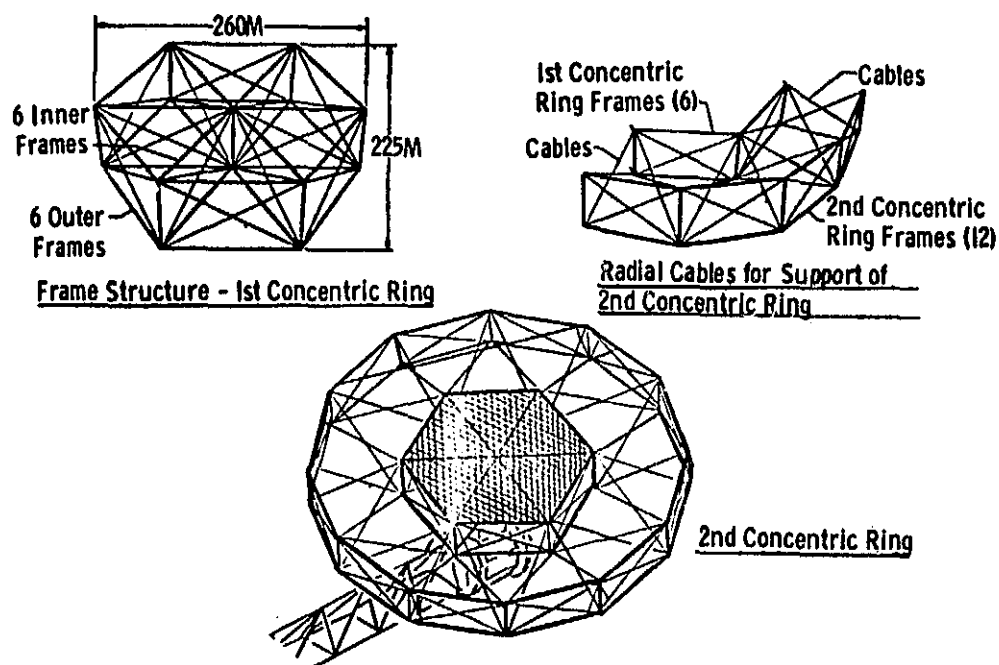


Figure 3.3.4-4 MPST - Concentric Ring Construction

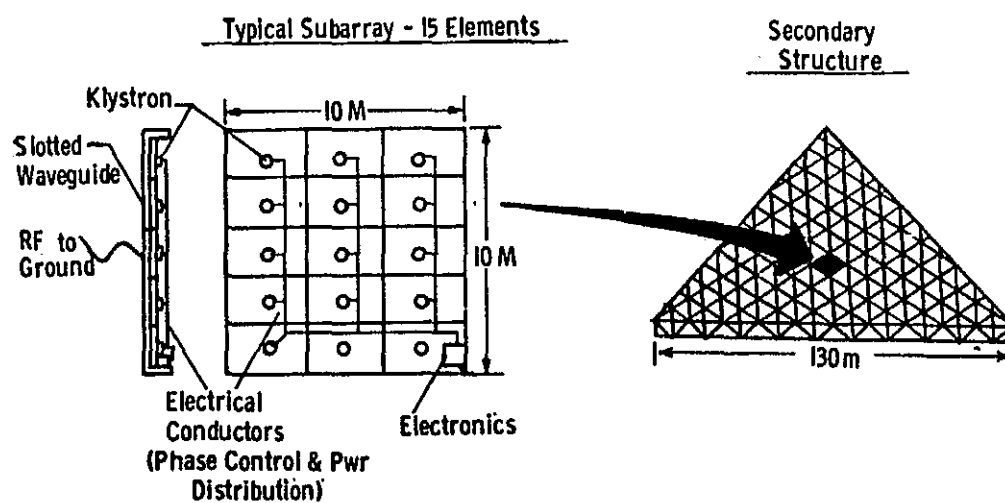


Figure 3.3.4-5 MPST - Subarray Placement in Secondary Structure

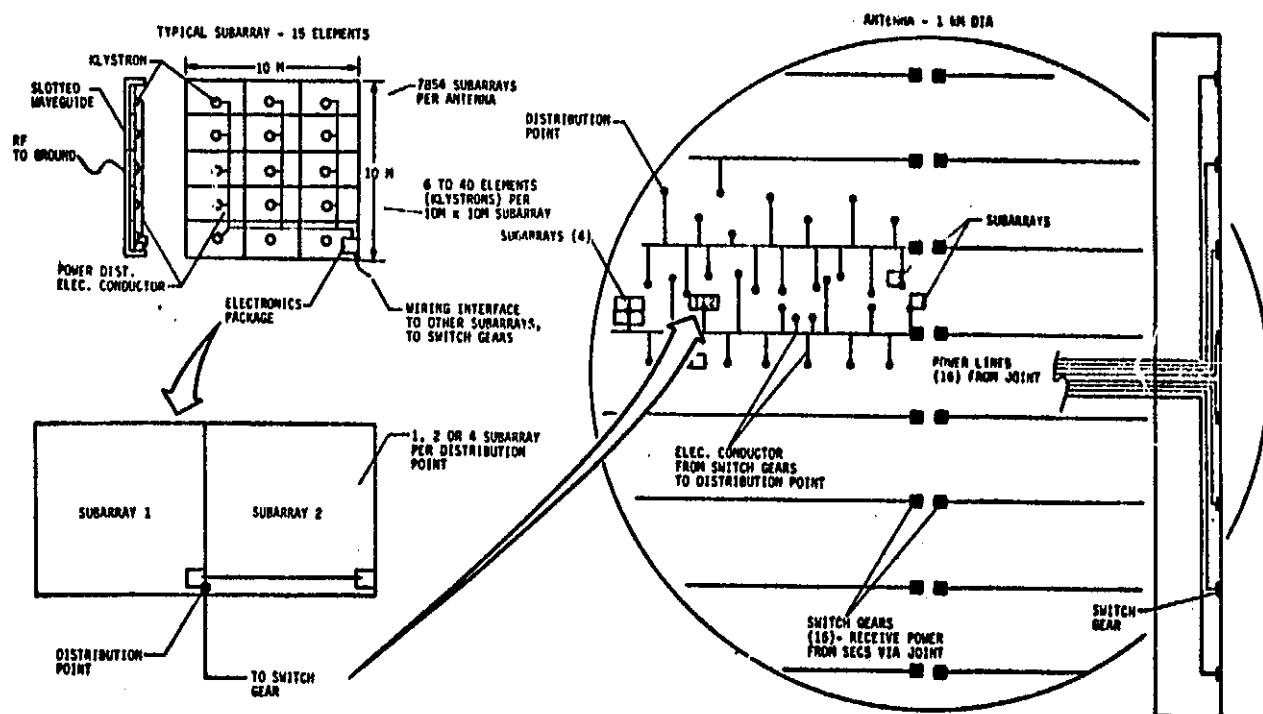


Figure 3.3.4-6 MPTS Power Distribution System

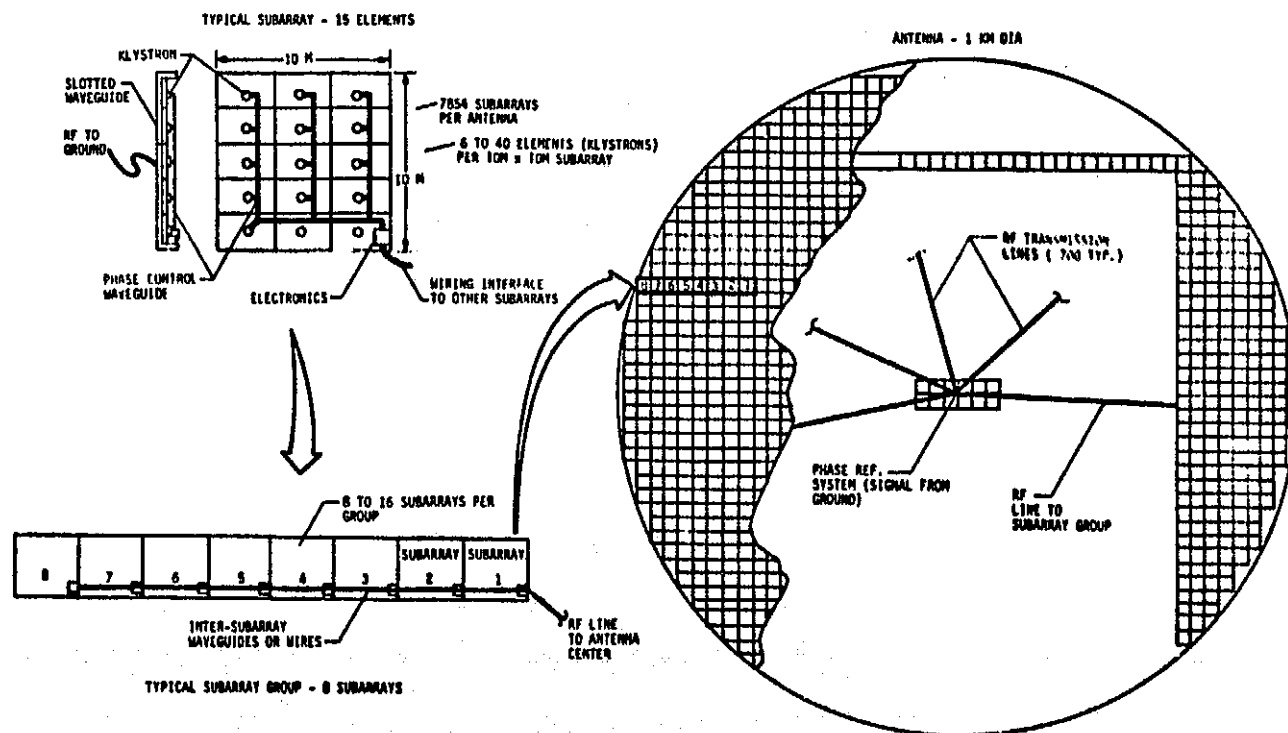


Figure 3.3.4-7 MPTS Phase Control System

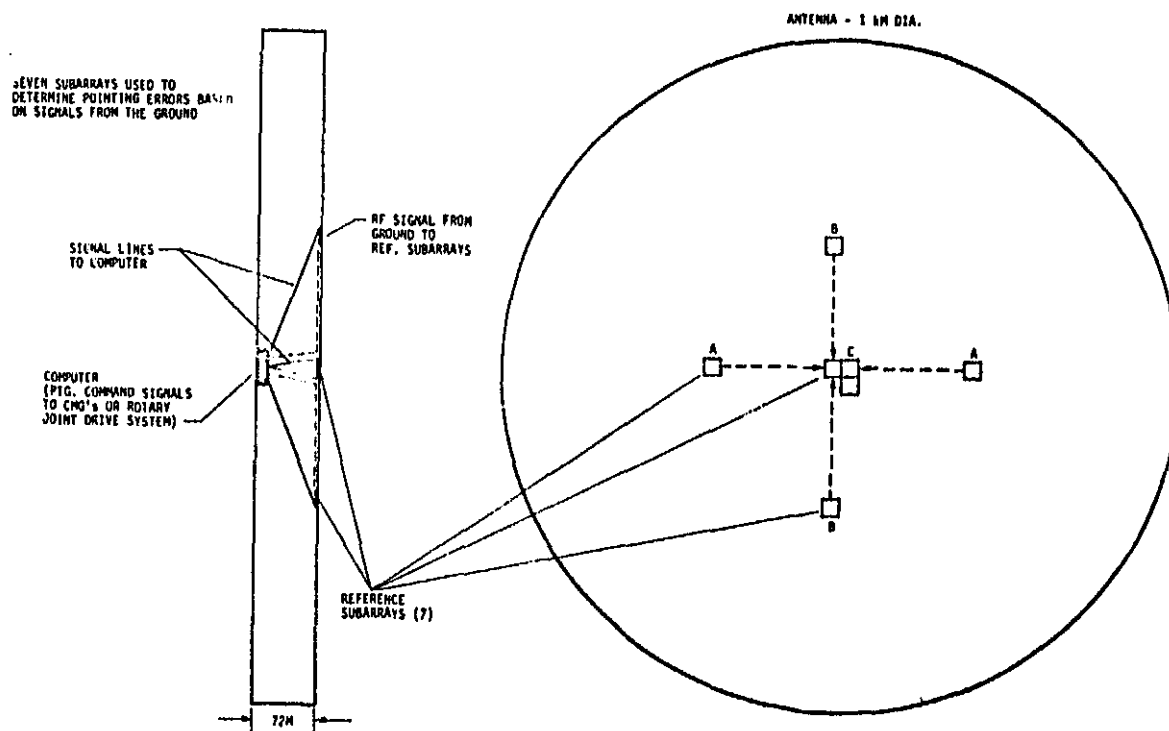


Figure 3.3.4-8 MPTS Pointing Control System

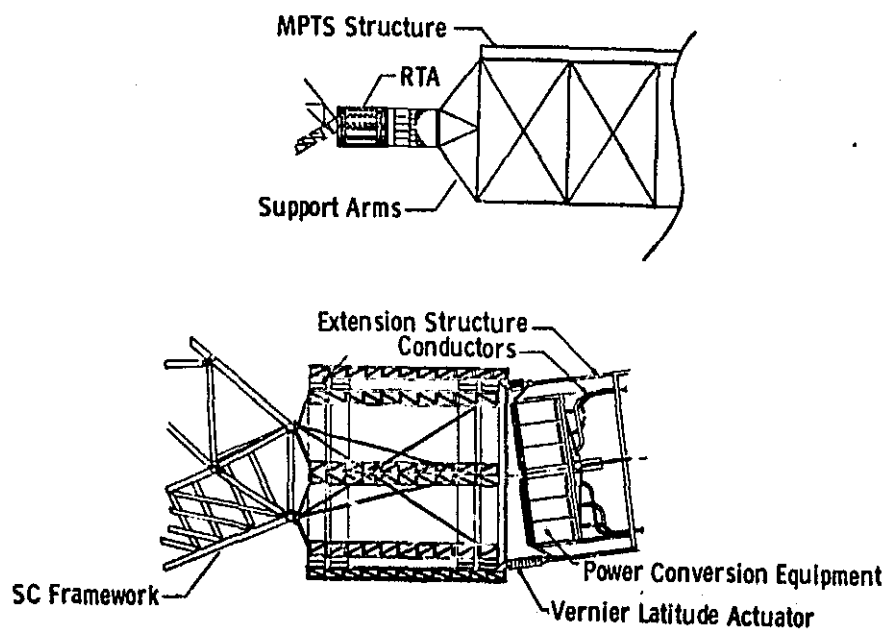


Figure 3.3.4-9 Thermal SPS - MPTS with Rotary Transformer Assembly

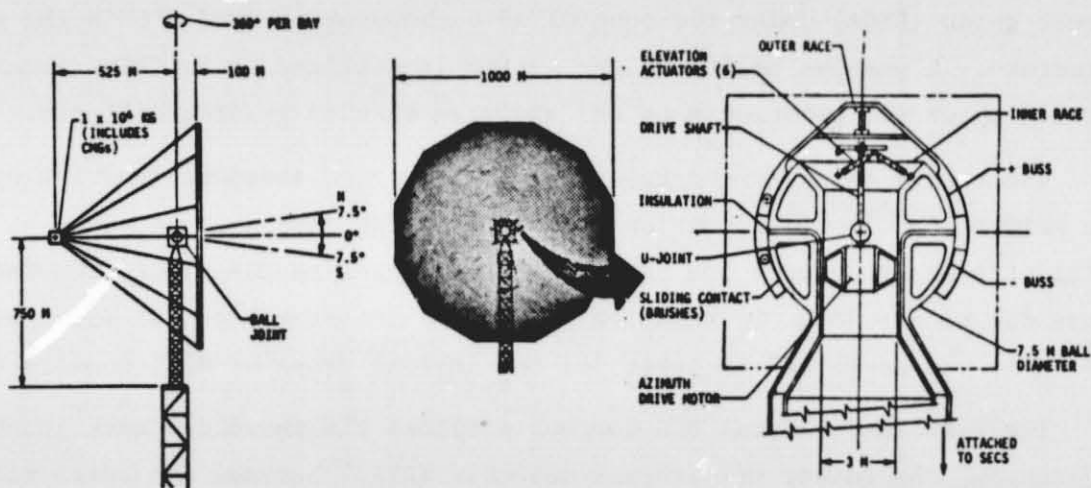


Figure 3.3.4-10 Column/Cable SPS - MPTS with Ball Joint

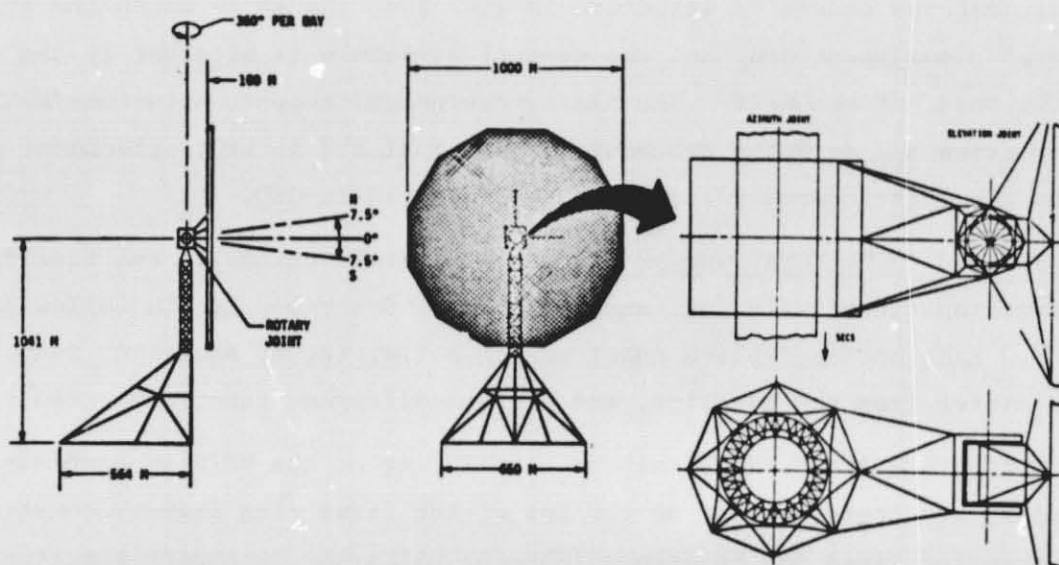


Figure 3.3.4-11 Truss Type SPS - MPTS with Rotary Joint

transmitting antenna. Actual antenna pointing is accomplished with control moment gyros (CMGs) under the control of a computer mounted within the antenna structure. A massive counterweight system is utilized to equalize moments of inertia about the pointing axes and minimize gravity gradient effects.

The rotary joint (truss-type SPS) contains two independent drive systems for azimuth (360°) and elevation ($\pm 7.5^\circ$) pointing, and acts as both the structural attachment between the SECS and the MPTS and as the power transfer path. Since the rotary joint is relatively massive, its structure and drive systems are built and assembled in orbit, as the initial steps of MPTS construction.

The baselined thermal SPS concept utilizes the third distinct joint configuration, the rotary transformer assembly (RTA), between the solar collection system and the transmitting antenna. The RTA is similar to the ball joint concept for the column/cable SPS in that it acts as the point of rotation for the antenna, and as the power transfer path.

Since the thermal SPS generates AC power, the RTA includes power conversion equipment (mounted within the extension structure) to produce a DC input to the microwave generators in the antenna. The extension and support structures for this concept are similar to those used for the ball joint concept, except that the extension structure is just long enough to house the power conversion equipment and that the support structure is attached to the side not the base, of the MPTS. The RTA/extension and support structure/MPTS construction and assembly procedure is accomplished in LEO; attachment of the RTA to the solar concentrator frame is completed in GEO.

3.3.4.3 MPTS Construction Options - Several options to the baseline MPTS construction technique exist, and are briefly described in the following paragraphs. Each option implies construction activities or equipment requirements which differ from the baseline, and present different functional requirements.

Option A - After the first concentric ring of the MPTS is completed, with secondary structures placed on the top of the first ring frames, construction of succeeding rings can be accomplished by using the secondary structures as the assembly/support base for the ring frames. Secondary structures for the second ring can be attached along one side to the secondary structures of the first ring (and attached to each other as succeeding structures are placed); then the frames of the second ring can be attached underneath the outermost sides of the second ring secondary structure. Three permanent attachments

would be made between each secondary structure and the underlying frames; temporary attachments would be made between the secondary structures. After the secondary structures and frames of the second concentric ring are in place, radial cables between the first and second ring frames can be installed and the temporary intersecondary structure attachments can be removed.

Option B - To minimize the necessity to work within the secondary structure at the back of the subarrays to connect electrical conductors and RF lines for the power distribution, phase control and pointing control systems, an alternative construction approach can be used. After the secondary structures are attached to the substructure (frames) and prior to attachment of the subarrays, the power conductors between the switch gears and the distribution point, the RF lines, and the pointing control wiring between the computer, drive system and positions of the reference subarrays can all be placed over the secondary structure. The lines could be tied to the structure at appropriate support points and contain connectors at the end for ultimate mating with the proper subarray. Intersubarray conductors for the power distribution and phase control systems can be made a part of initial subarray fabrication; connections between subarray would be made when the subarrays are attached to the secondary structure. (The subarray design would have to allow for clearance for the various conductors between the subarray back face and the secondary structure.)

MPTS Construction Option C - It is assumed that the subarrays, as fabricated in and delivered from the manufacturing facility, include in preprogrammed lengths and positions all the required RF lines, electrical conductors (for the power distribution system), and pointing control wires. The transport, handling and fastening of these individual elements after subarray installation in the secondary structures is no longer required. This assembly option requires that each of 7854 subarrays be designated for a specific location on the MPTS surface. This would allow the phase control lines (RF), power distribution conductors, and pointing control lines to be incorporated into the subarrays during their fabrication in the MF. As each subarray is attached to the surface of the secondary structures during MPTS assembly, the intersubarray connections would have to be accomplished (either automatically or via manual operations).

Such an assembly technique would eliminate the requirement to locate and support long (up to 500 meter-lengths) RF or signal lines at the back side of

the subarrays within the secondary structure after initial subarray installation. Long-length conductors must still be installed, however, between the 16 switch gears mounted in the base of the secondary structures and the subarray distribution points (groupings of one to four subarrays). Up to 1000 distribution points, at distances of up to 500 meters from the switch gears, will be located on the MPTS. Thus, although this construction option eliminates some "cable stringing" requirements, it does not eliminate all such requirements and also adds complexity to subarray fabrication and installation.

3.3.5 Consideration of Man's Participation During Construction

The functional analyses tables presented in the preceeding paragraphs for each SPS concept contain a preliminary assessment of man's potential role in each construction task. Both the maximum and minimum possible use of man are identified in the tables so that the potential extent of man's role during SPS construction could be measured against the use of automated equipment.

Previous manned space programs, especially Skylab, have amply demonstrated man's utility in space and have provided large amounts of empirical data to guide the functional allocation between man and machine in new space systems designs. The approach was to survey previous efforts and to modify these efforts with MMC's experience, resulting in a definition and catalog of man's capabilities and limitations. The functional allocations between man and machine for actual construction were based on tradeoffs of several criteria. One of the primary criteria was the number of times a particular function must be performed. The more frequent functions could be allocated to a machine with the development cost amortized over many operations. The infrequent functions could be assigned to man, depending upon additional criteria. These other criteria include the availability of man and the hazards associated with using him.

Man's participation modes range from shirtsleeved control of equipment operations from a remote location, to a suited mode for direct EVA tasks. Figure 3.3.5-1 depicts the various potential roles anticipated for SPS construction.

The primary reasons for placing man in orbit to support orbital construction are his judgment and flexibility. Potential EVA tasks are considered to be options, where man can effectively perform infrequent or contingency type operations.

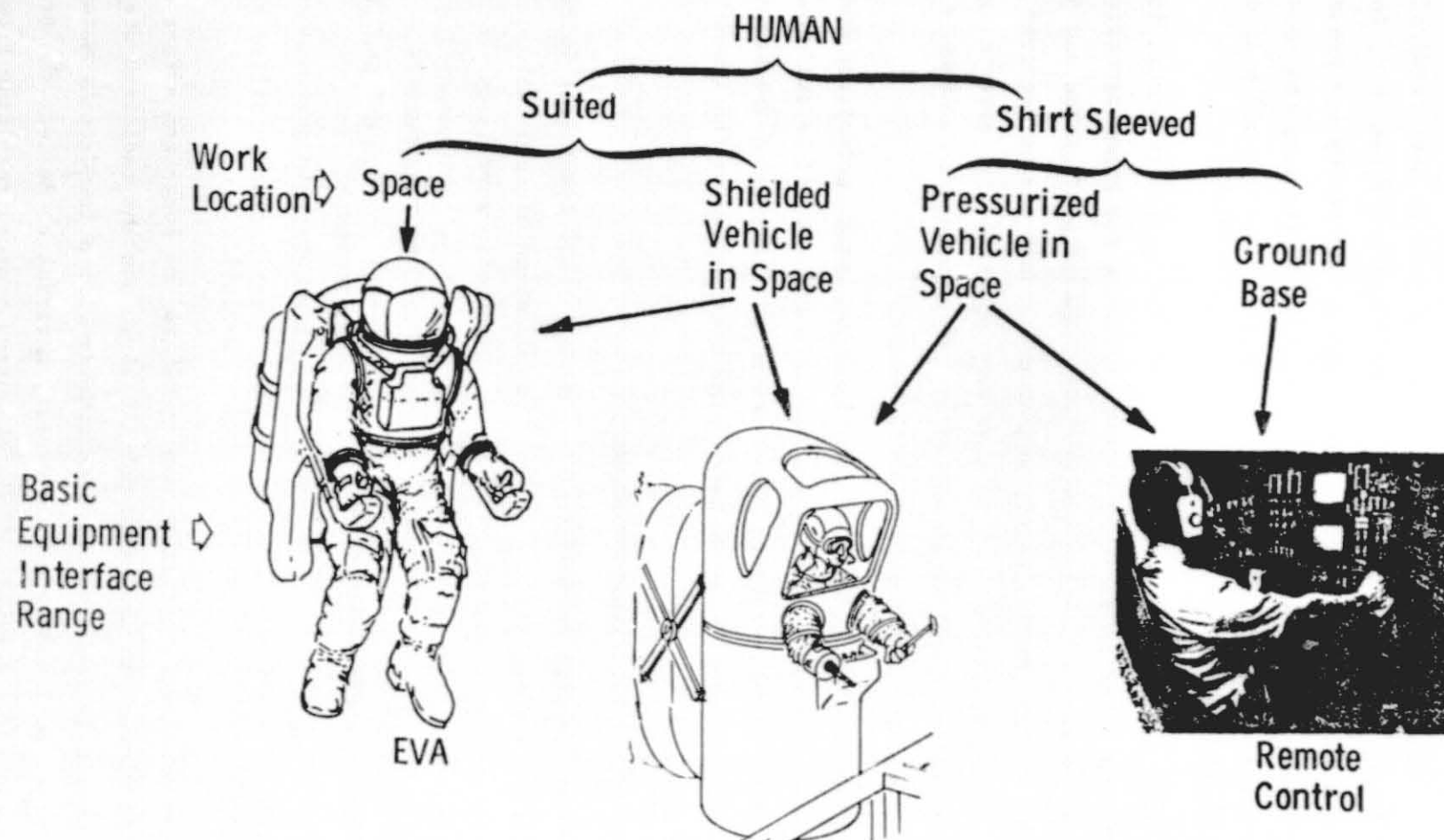


Figure 3.3.5-1 Man's Construction Task Participation Modes

Manned EVA can be used for force applications such as that required for aligning and mating parts where the man can react against a handhold, foot restraint or other hard point. Man, even though encumbered by the pressure suit and thick pressurized glove, still has high dexterity compared to a machine. This dexterity can be used for assembly of small or odd shaped parts, repair and resupply.

Man's visual acuity makes him very valuable for precision visual inspection; however, x-ray and other sensors may be more valuable for other situations. The EVA crewman can perform effective qualitative inspection of cables and joints, although torque meters, strain gages, and other sensors may be required for more quantitative inspection. Man is also very adaptable for performing contingency inspection such as visual sightings for alignment measurements and electrical measurements at suspect connectors.

Based on the mission scenarios, functional analyses, guidelines and man's availability, the crewman's performance participation should be evaluated on an integrated mission level. Table 3.3.5-1 presents a listing of the major parameters that should be considered in developing and displaying the feasibility of using man in space.

Table 3.3.5-1 Man's Participation Parameters

- | | |
|---|---|
| • Distance from worksite to shelter | • Number of times task is repeated |
| • Accessibility to worksites | • Duration of each task |
| • Accessibility to work tasks | • Metabolic work loads |
| • Configuration of worksite | • Radiation environment and parametric shielding requirements |
| • Masses manipulated | • Thermal environment and control requirements |
| • Joining techniques/fastener types | • Micrometeoroid environment |
| • Visibility constraints | • Contamination-sensitive areas at worksites |
| • Construction base support facilities and interfaces | |

The major problem in utilizing man in GEO is the long-term effect of radiation, which is minimal in low earth orbit. To reduce the radiation dose to man, a composite shield is required which is comprised of a low-density material to absorb electrons, followed by a high-density material to deflect the Bremsstrahlung (penetrating secondary x-rays). The high-energy protons resulting from solar

flares present a more difficult shielding problem than electrons. Therefore, a strategy based upon solar prediction, coupled with a well shielded area of retreat, may be applicable. Since the effects of radiation are cumulative with time, the longer a crew is on-orbit, the more time spent in suited EVA, and the less protection received from the EVA suit, the more protection the habitat must provide.

The predicted effects of radiation on man are severe for foreseeable GEO dose rates (reference, Bioastronautics Data Book, NASA SP-3006). It appears that to protect the GEO crewman from any predictable effects of radiation, the weight of the shielding and/or the frequency of crew rotations may be prohibitive. Table 3.3.5-2 summarizes the relationship between radiation dosage, time in GEO and shielding required.

Table 3.3.5-2 Ionizing Radiation in GEO vs Shielding Thickness

ACCUMULATED DOSE (REM)	TIME	EFFECTIVE ALUMINUM THICKNESS REQUIRED IN GEO	
		FOR QUIESCENT SUN (MILS)	FOR ACTIVE SUN
270	365 Days	700	800
130	120 Days	600	700
70	30 Days	220	380
50	7 Days	140	270
24	8 Hours	90	130
• Should cause no injury to blood forming system • ~50% probability of some change in ocular lens • Reduced fertility • At least a two year loss in life expectancy • About 10% probability of male sperm mutations			

Despite the radiation hazard (which it is assumed will be effectively controlled), it is anticipated that man will perform both IVA and EVA functions in orbit. In either, he can perform directly with his hands as manipulators and eyes as sensors, or he can use controls and displays to perform the task. A man using controls and displays can use computing machines to augment his capabilities by simplifying (such as quickening) the display or control. The computer can assume some or all of the control function relegating man to an interactive supervisory or observer role.

Many of man's inherent capabilities are extremely difficult to build into a machine. Man is very versatile with the ability to easily change from performing one function to another. His adaptive capacities allow him to easily change his responses based upon previous feedback or observed anomalies.

However, most important of man's capabilities is judgment, which includes the ability to devise heuristic procedures and take action in the face of uncertainties. For example, man can estimate probabilities and eventualities, evaluate alternatives, perceive what is relevant and utilize previous experiences in novel situations, improvise, see relationships, select appropriate procedures, and usually arrive at decisions within existing time and environmental limitations. Table 3.3.5-3 summarizes the advantages and disadvantages of man's utility in space.

Even with the program assumption to use automated equipment wherever possible, it is anticipated that man will play a continually increasing part in orbital construction assembly during the development progression. With the availability of man on orbit, he will also play an increasing role in contingency operations resulting in a higher mission success probability.

Table 3.3.5-3 Man's Utility in Space

ADVANTAGES	DISADVANTAGES
• Versatility • Adaptive capabilities • Ability to effectively utilize feedback • Ability to use judgment, devise heuristic procedures, and take corrective action	• Must work in tightly controlled life supporting environment • Easily bored or fatigued with low vigilance reliability • Limited channel capacity, computational abilities poor, has trouble controlling parallel operations • Poor at producing rapid and uniform outputs

3.3.6 Summary of Results - Construction Scenarios/Functional Analyses

The detailed understanding of potential SPS configurations achieved by developing construction scenarios and functional analyses provided the basis for identifying OCSE requirements. That is, the scope of the tasks to be performed by the support equipment was defined in broad terms by giving

visibility to the entire construction sequence. The actions to be performed upon separate SPS elements were identified as distinct steps in the assembly process. SPS elements are integral components, structural assemblies or subsystems which together comprise a complete SPS. The depth to which the analyses of the individual steps were completed was sufficient to allow categorization of the requirements in generic terms.

3.4 Generic Processes for SPS Elements

3.4.1 Generic Processes Summaries

Based on the construction tasks identified in the functional analyses of the baseline SPS concepts investigated, requirements were identified for performing the SPS construction tasks on each SPS element. These requirements are summarized in Generic Processes Requirements Tables 3.4.1-1 thru 3.4.1-7. These tables were generated for each of seven particular processes. Cumulatively, these processes encompass all functions required during SPS construction/assembly. Individually, each process is defined such that it includes a specific type of activity. The SPS elements may involve activities relating to any or all of the generic processes. The processes are defined as follows:

a. Transport - To carry from one place to another (e.g., take package of beams from logistics facility to remote installation site on SPS).

b. Handle - To manipulate an item from one location and/or orientation to another, with specified placement requirements (e.g., take beam from fabricator and position it for attachment into structure).

c. Align - To position and verify an item is in a specific desired location prior to fastening (e.g., adjusting a beam location prior to welding the ends in place).

d. Fasten - To join, connect, or attach where some specific action is taken after positioning the item (e.g., welding or screwing joints together).

e. Adjust - To reposition a previously fastened item (in orientation or location) by applying force through another element of the total system. (e.g., tensioning of cables, adjusting vernier).

f. Monitor - To evaluate conditions (e.g., verification of alignment or viewing progress of adjustment by remote optics or direct viewing).

g. Checkout - To verify task completion or equipment operation (e.g., measuring instruments, display devices, and interpretation of data).

Requirements were identified for each process applicable to each SPS element, for every recognized task involved in the baseline construction methods. Unique tasks applicable to construction options were added as deltas. In addition, tasks were added and analyzed for other construction operations in the maintenance and repair categories. Table 3.4.1-8 summarizes the general maintenance tasks considered and potential application to the baselines.

Table 3.4.1-1 Generic Process Summary - Transport

SPS ELEMENT	SOURCE	FUNCTIONAL CHARACTERISTICS						
		MASS (UNIT/TOTAL)	CONFIGURATION	DISTANCE	PROCESS CYCLES	SUPPORT REQUIREMENTS	CONSTRAINTS	ATTACHMENT CONSIDERATIONS
Facility Beams Note: Beams transported if not handled.	C/C facility (1.1.4)	36 kg each	2.45 m triangular x 110 m long	50 to 100 m	15		Access on and through facility framework. Beam assembled from thin materials.	Attachment loads should be spread over large surface area.
	TT facility (1.1.4)	837 kg each	10 m triangular x 650 m long	50 to 1300 m	118		Access on and through facility framework. Beam assembled from thin materials.	Attachment loads should be spread over large surface area.
	BT facility	215 kg each	8 m square x 125 m long	Up to 300 m	3			Attachment loads should be spread over large surface area.
Column Hub Beams	C/C (3.1)	10 to 40 kg each	2.45 m triangular x 5 to 112 m long	~200 m	31		Access on and through facility framework. Beam assembled from thin materials.	Attachment loads should be spread over large surface area.
Cable Reels (from LF to CF)	A/R	Secondary tapes: ~10 kg each 2400 kg total	Packaged - TBD	Up to 13 miles through space. Up to 18 miles maintaining structure contact.	One 2400 kg package to each of 2 facilities. One 1800 kg package to each of 2 facilities.			Packaged.
		Peripheral cables: 682000 kg each.	Reel		2 to each of 4 facilities.			Reel packaged - large volume, 188 m ³ each.
Solar Cell Packages	C/C (4.1.3.1)	Maximum package mass 48,000 kg. Progressively less mass per package.	Maximum package 10 x 10 x 8 meters. Progressively smaller packages.	Up to 13 miles through space. Up to 18 miles maintaining structure contact.	120 packages			Packaged in groups.
Concentrator Material	C/C (4.1.3.1)	Maximum package mass 5000 kg. Progressively less mass.	100 meter long rolls.	Up to 13 miles through space. Up to 18 miles maintaining structure contact.	240 rolls			Packaged in groups of rolls.
Solar Cell Blanket Installers	TT facility (1.2.2)	Mount - TBD Total solar cell material 7 x 10 ⁶ kg	End mounts. Materials on rolls 650 m long.	From LF to installation point - 3900 meters max.	Mounts - 24 SC rolls - 4 Concentrator rolls - 8			
Concentrator Installers		Mount - TBD Total concentrator material - 7 x 10 ⁵ kg.	SC roll > 14 m diameter if all one roll.					
Tension Cable Installers	TT facility (1.2.3)	TBD	TBD	From LF to installation point - 2600 meters max.	30			
Power Distribution Harness Installers	TT facility (1.2.4)	163,000 kg each installer (with 4 12 cm cables on each installer)	TBD	From LF to installation point - 2600 meters max.	4 (2 at each end wall)			
Auxiliary Facility Equipment	TT facility (1.2.5)	TBD	Propulsion modules ACS modules GN I C module 20 estimated	From LF to installation points - 3900 meters max.	~20	Provisions for aligning modules.		
Auxiliary SPS Equipment	TT (3.1.11)	355,000 kg total - assume 7000 kg each	ACS modules.	Installed within facility Up to 2600 meters.	~50		Propellant hazards if damaged.	
		4000 kg total TBD per unit	I & C modules	Installed within facility Up to 2600 meters.	TBD			
		TBD	Auxiliary equipment mounting provisions.	Installed within facility Up to 2600 meters.	~54			
PCS Stanchions	BT facility (1.1.4)	~25 kg	Rod with base structure	Up to 300 m	4 (each facility)			
Cavity Absorber Shell	BT (2.1.1.1)	~53,000 kg each	20 x 29m panel sections.	Up to 300 m	98 (each module)			Could package into larger package.
Turbogenerator Sets	BT (2.1.1.3)	~236,400 kg each	Heavy machinery and tanks joined in package ~20 x 29 x 5 m.	Up to 300 m	16 (each module)			Could be broken into smaller units.
SC Framework Secondary Structures	BT (2.1.2.5)	~5000 kg each	Pop out structure deploys to 225 m equilateral triangle x 10 meter thick.	From CF to installation site: attached to SPS structure ~5000 m max. Free-flying ~2700 m max.	762 (each SPS module)			

Table 3.4.1-1 (Continued)

SPS ELEMENT	SOURCE	FUNCTIONAL CHARACTERISTICS						
		MASS (UNIT/TOTAL)	CONFIGURATION	DISTANCE	PROCESS CYCLES	SUPPORT REQUIREMENTS	CONSTRAINTS	ATTACHMENT CONSIDERATIONS
Reflector Facets	BT (2.1.2.6)	~65 kg each	Flat hexagonal material stretched between tension structures at 3 sides.	From CF to installation site: attached to SPS structure ~5600 m max. Free-flying ~2700 m max.	17,000 (each SPS module)			
MPTS	BT (2.1.4.2 and 4.2.1)	21 x 10 ⁶ kg	Complete assembled MPTS with rotary transformer assembly.	Order of miles.	2	Station keep capability. Capture by manipulator from SC structure.		
Spinal Trusses Between PCSs	BT (4.1.3)	TBD	10 meter trusses	~4000 meters	3 spans			
Construction Equipment	C/C option A	TBD	Handling equipment for installing SECS equipment.	~6000 meters from CF to center of SECS supports.	As required.		Transportation inside 100 meter column is desirable because of main cables on outside of column truss.	
Solar Cell Packages	C/C option A	Unit packages 4,000 to 50,000 kg. Total per side of SECS 28.7 x 10 ⁶ kg.	Packages 10 x 10 m by thickness of 0.1 to 8 meters.	Up to 6000 meters.	As required depending on packaging.			
Concentrator Rolls	C/C option A	Unit rolls 4,000 to 50,000 kg.	Rolls 100 meters long x up to 1.0 meters diameter.	Up to 6000 meters.	120 rolls per side of SECS			
Secondary Tape Reels	C/C option A	~10 kg each	Small reels.	Up to 12,000 meters.	As required depending on packaging. 844 reels total.			
Automated Construction Equipment	TT option A	TBD	TBD	Up to 2600 meters from LF.	Estimate 35 places.			
Long-Bow SC Construction Equipment	BT option A	Estimated 8,000 kg.	Long truss structure with attached mobile manipulators.	TBD	Installed once.			
Solar Cell Roll and Mounts	C/C option B	Rolls = 48,000 kg max. Mounts = 200 kg each.	100 m long rolls.	LF to CF = 13 miles FF, 18 miles attached. CF to Site = 6000 meters.				
Resupply Beam Builders	Planned unscheduled service.	TBD	Stock material on rolls.	LF to C/C CF = 13 miles FF, 18 miles on structure. LF to TT beam builder = 2600 meters. LF to BT beam builder = 2700 m free flying, 5600 m attached.	A/R			
SPS Commodity Modules (e.g. ACS Tanks)	Planned unscheduled service.	TBD	Compact package on order of 1 m ³ in volume.	C/C = 13 miles FF, 18 miles on structure. TT = up to 17 km BT = up to 2700 m free flying, 5600 m attached.	A/R		Need to be hard attached to structure to make module exchange.	
Fastening Device Resupply	Planned unscheduled service.	TBD	Materials used in fastening devices (e.g. weld material, glue)	C/C = LF to CF 13 miles FF or 18 miles on structure. CF to fastener less than 200 m. TT = less than 4 km. BT = up to 2.7 km FF or 5.6 km attached to structure.				
Lubrication	Planned/scheduled maintenance.	Small unit operated by EVA crewman.	Lubricate construction equipment.	C/C = 200 m TT = 4 km BT = 5.6 km			Environment impacts and induced effects.	Assume EVA crewman.
Remove Reflector Facet Layer	Planned/scheduled maintenance.	TBD	EVA crewman or remote-control free flyer EOTS.	BT only = ~2.7 km.	Repeated for 67,000 facets during SPS 30 year life.	Disposal storage	Potentially hot environment.	
Helium and NaK System Recharge	Planned/scheduled maintenance.	Service cart (TED).	Service cart with large NaK supply tank.	BT only = up to 9 km free flying.	A/R	Assume requires EVA crewmen for operating equipment.		
Troubleshooting	Contingencies	115 = 225 kg estimate. TBD	EVA crewman with instruments. Remote controlled viewing device.	C/C = up to ~16 km. TT = up to ~23 km. BT = up to ~10 km.			Environment	
Personnel Rescue	Contingencies	~200 kg	Single person.	C/C = up to ~16 km. TT = up to ~23 km. BT = up to ~10 km.	A/R			

Table 3.4.1-1 (Continued)

SPS ELEMENT	SOURCE	FUNCTIONAL CHARACTERISTICS				SUPPORT REQUIREMENTS	CONSTRAINTS	ATTACHMENT CONSIDERATIONS
		MASS (UNIT/TOTAL)	CONFIGURATION	DISTANCE	PROCESS CYCLES			
Return Failed Parts to Shop	Contingencies	TBD	Multiple person vehicle.	In vicinity of facility.	A/R	Provisions for docking while removing module.	Interferences in dense-structure areas.	
		Estimated 20 - 500 kg.	Mobile/portable construction equipment.	Up to 5 km.				
Repair Failed Parts On-Site	Contingencies	Estimated 100 - 2000 kg.	SPS operational modules (e.g. subarrays)	MPIS - 1 km C/C - 16 km free-flying, 22 km structure attached. TT - 14 km max. BT - 10 km max. free-flying.	A/R	EVA crewman system with repair kit.	Environment.	
		TBD (<100 kg est plus CM)	Material separation: - C/C and TT concentrator - BT reflector	Up to 16 km. Up to 10 km.				
		Service Cart (TBD) (>1000 kg est plus CM)	System leak on BT PCS.	Up to 9 km.				
		TBD (<100 kg est plus CM)	Cable break: - C/C SECS support. - TT tension rods. - MPIS primary structure.	Up to 14 km. Up to 15 km. Up to 5 km.				
		TBD (<100 kg est plus CM)	Electrical conductor break: - C/C peripheral cable. - TT power cable. - MPIS power cable.	Up to 10 km. Up to 3 km. Up to 1 km.				
		TBD (<100 kg est plus CM)	Component replacement: - C/C tape reel. - TT ACS sensor. - BT transformer.	Up to 14 km. Up to 15 km. Up to 5 km.				
		TBD (>200 kg est plus CM)	Construction equipment repair.	Up to 4 km.				
Electrical Conductors (Between Joint & SECS)	C/C MPIS 4.2.1.3 4.2.2.3 TT MPIS 3.2.1.3 BT MPIS	63 kg/meter C/C: 47,250 kg/conductor TT: 63,000 kg/conductor BT: 4,725 kg/conductor	C/C: 750 m long each TT: 1 km length each BT: 75 m 17 cm dia. - 4 conductors	C/C: LF to MPIS 12.7 miles FF 18 miles attached TT: CF to Joint - 1 km	1	None	Cable avoidance (C/C).	Could be transported on reels.
Ball Joint	C/C MPIS 4.2.2.1		Cylinder, 11 m dia.	LF to MPIS 12.7 miles FF 18 miles attached	1	None	Cable avoidance (C/C).	None
Frames	C/C MPIS 4.2.3.1 TT MPIS 3.2.3.1 BT MPIS 2.2.1.1	140/9240 kg (308/20328 lbs.)	65 m x 130 m rectangles with diagonal cables	CF to MPIS C/C: 750 m TT: 1000 m BT: <100 m	66		Cable avoidance (C/C).	
Secondary Structures	C/C MPIS 4.2.3.2 TT MPIS 3.2.3.2 BT MPIS 2.2.1.2	1200/115200 kg (2640/253440 lbs)	Triangle 130 m on each side, 7 m high.	C/C: LF to MPIS 12.7 mi FF 18 mi attached TT: CF to MPIS, 1 km BT: CF to MPIS, <100 m	96		Cable avoidance (C/C).	
Subarrays	C/C MPIS 4.2.4.2 TT MPIS 3.2.4.2 BT MPIS 2.2.2.2	200/1570800 kg (440/3455760 lbs)	10 m x 10 m x .25 m each	C/C: LF to MPIS 12.7 mi FF, 18 miles attached TT: CF to MPIS, 1 km BT: CF to MPIS, <100 m	7854		Cable avoidance (C/C).	Probably transported in several packages (e.g. 8 40 m x 40 m x 40 m packages)
Electronics Packages Interconnects (elec. conductors)	C/C MPIS 4.2.5.1 TT MPIS 3.2.5.1 BT MPIS 2.2.3.1		Small dia., 10 m lengths each.	C/C: LF to MPIS, 12.7 miles FF, 18 miles attached TT: CF to MPIS 1 km BT: CF to MPIS, <100 m	~7000		Cable avoidance (C/C).	
RF Lines	C/C MPIS 4.2.5.2 TT MPIS 3.2.5.2 BT MPIS 2.2.3.2		Small dia., lengths between 10 and 500 m.	C/C: LF to MPIS, 12.7 miles FF, 18 miles attached TT: CF to MPIS 1 km BT: CF to MPIS, 100 m	~700		Cable avoidance (C/C).	Could be transported on reels.

Table 3.4.1-1 (Concluded)

SPS ELEMENT	SOURCE	FUNCTIONAL CHARACTERISTICS						
		MASS (UNIT/TOTAL)	CONFIGURATION	DISTANCE	PROCESS CYCLES	SUPPORT REQUIREMENTS	CONSTRAINTS	ATTACHMENT CONSIDERATIONS
Switch Gears	C/C MPTS 4.2.6.1 TT MPTS 3.2.6.1 BT MPTS 2.2.4.1	2000 kg/22000 kg 4400 16/70400 lbs	Blackbox	C/C: LF to MPTS 12.7 m FF, 18 m attached TT: CF to MPTS, 1 km BT: CF to MPTS, <100 meters	16		Cable avoidance (C/C).	
Electrical Conductors (between joint bus and switch gears)	C/C MPTS 4.2.6.2 TT MPTS 3.2.6.2 BT MPTS 2.2.4.2	15.75 kg/m 4 @ 6450 kg each 4 @ 7875 kg each 4 @ 6500 kg each 4 @ 4725 kg each	Lengths: 4 @ 600 m 4 @ 500 m 4 @ 400 m 4 @ 200 m Small dia (8.5 cm dia ea)	C/C: LF to MPTS 12.7 m FF, 18 m attached TT: CF to MPTS 1 km BT: CF to MPTS <100 meters	26		Cable avoidance (C/C).	Reel
Electrical Conductors (between switch gears and distribution points)	C/C MPTS 4.2.6.3 TT MPTS 3.2.6.3 BT MPTS 2.2.4.3	15.75 kg/m 4 @ 7875 kg each 4 @ 6500 kg each 4 @ 4725 kg each 4 @ 3150 kg each 1000 @ 1575 kg	Lengths: 4 @ 500 m 4 @ 400 m 4 @ 300 m 4 @ 200 m 1000 @ 100 m (8.5 cm dia each) 10 m lengths	C/C: LF to MPTS 12.7 m FF, 18 m attached TT: CF to MPTS 1 km BT: CF to MPTS <100 meters	~1000		Cable avoidance (C/C).	Reel
Electrical Conductors (to distribution points between subarrays)	C/C MPTS 4.2.6.4 TT MPTS 3.2.6.4 BT MPTS 2.2.4.4			C/C: LF to MPTS 13 m FF, 18 m attached TT: CF to MPTS 1 km BT: CF to MPTS <100 meters	~7000		Cable avoidance (C/C).	
Support Gears Counterweight Gears	C/C MPTS 4.2.7.1	54/6450 kg (119/14255 lbs)	150 m long each	CF to MPTS ~750 meters (5.9 mΔ)	720			
Counterweights (including CMGs)	C/C MPTS 4.2.7.2	10 ⁶ kg	50 m x 50 m x 50 m	LF to MPTS 13 miles FF, 18 miles attached	1 (unless transported in pieces)			
Computer	C/C MPTS 4.2.8.1 TT MPTS 3.2.8.1		YED	C/C: LF to MPTS, 13 m FF, 18 m attached TT: CF to MPTS 1 km	1		Cable and structure avoidance.	
Wiring (between computer, reference subarrays and drive system counterweight for C/C, rotary joint for TT)	C/C MPTS 4.2.8.2 TT MPTS 3.2.8.2		Lengths: 3 @ 75 meters } C/C 2 @ 200 meters } 2 @ 300 meters } TT plus 1 @ 625 m for C/C, 1 @ 100 m for TT	C/C: LF to computer 13 miles FF, 18 m attached TT: CF to computer 1 km	8 lines		Cable and structure avoidance.	Reel
Drive System and Power Transfer Mechanism (in rotary joint)	TT MPTS 3.2.2.2 3.2.2.3		YED	CF to rotary joint axle joint and elevation joint 1 km.	1 step			
Electrical Conductors (rotary joint buses)	TT MPTS 3.2.2.4 3.2.2.5 3.2.2.6		Small dia. lengths of 25 m, 150 m, 25 m.	CF to joint, 1 km	1 step			
Rotary Transformer Assembly (RTA)	BT MPTS 2.2.8.1		20 m dia	CF to joint, ~100 m	1			
Power Conversion Equipment and Filter	BT MPTS 2.2.8.2			CF to joint, ~100 m	1 step			
Radial Cables	C/C MPTS 4.2.3.1 TT MPTS 3.2.3.1 BT MPTS 2.2.1.1		Lengths: 35 @ 150 m each 144 @ 175 m each	C/C: LF to MPTS 13 m FF, 18 m attached TT: CF to MPTS 1 km BT: CF to MPTS <100 meters	780 cables		Structure avoidance.	Reels

Table 3.4.1-2 Generic Process Summary - Handle

SPS ELEMENT	SOURCE	FUNCTIONAL CHARACTERISTICS							
		MASS (UNIT/TOTAL)	CONFIGURATION	DISTANCE	PROCESS CYCLES	POSITIONING ACCURACY	SUPPORT REQUIREMENTS	CONSTRAINTS	GRIP CONSIDERATIONS
Facility Beams	C/C facility (1.1.4)	36 kg each	2.45 m triangular x 110 m long	~70 m	15	Locate beam ends within 1 cm lateral, 50 angular insert in nodal drogue fitting.	Lighting maintained throughout facility area.		Grip beam at 2 points or over large area to minimize deflections and local stresses. Possibly 2 handlers holding at beam end fittings.
	TT facility	837 kg each	10 m triangular x 650 m long	50 to 300 m	118	Locate beam ends within 1 cm lateral, 50 angular insert in nodal drogue fitting.	Lighting maintained throughout facility area.		
	BT facility	215 kg each	8 m square beam x 125 m long	125 meter	6	Hold for mechanical fastening or weld.	Lighting.		
Beam Builders	C/C Facility (1.1)	15,000 kg each	Cylindrical 5 m dia x 15 m	50 m	6 (per CF)	Hold for mechanical fastening or weld.	Lighting.		
Construction Equipment	C/C facility (1.1.2) TT facility	TBD	TBD	TBD	TBD				
Tension Rods	C/C (1.1.4 and 3.0)	~5 kg	Small diameter filament with probe end fitting and adjustment, e.g. turnbuckle.	141 m	Facility - 12 Column: 864 at 4 facilities 431 at 2 facilities	Hold for mechanical fastening or weld.	Lighting.		
Column Hub Beams	C/C (3.1)	10 to 40 kg each	2.45 m triangular x 5 to 112 m long	~100 m	31	Hold for mechanical fastening or weld.	Lighting.		(Same as above)
Column Beams	C/C (3.2, 4.1.1)	36 kg each	2.45 m triangular x 100 m long	~70 m	867 at 4 facilities 435 at 2 facilities	Hold for mechanical fastening or weld.	Lighting.		(Same as above)
Facilities (dock to hub)	C/C (3.3)	~1200 kg plus base facilities	100 m triangular x ~200 m long	Docking placement (facility ACS provides gross placement)	5	Simultaneously insert three probe end fittings - 1 cm lateral, 1 min. angular.	Lighting. Video viewing or EVA crewmen (3).		(Same as above) Need to grip all 3 points of facility to prevent bending loads.
Main/Prime Cable Reels (initial installation)	C/C facility (3.0)	~40 kg		200 meters	96 reels at CF-1 and CF-3				
Main Cables	C/C (4.1.2.1)		Deployed from facilities by reels. Final length up to 12.7 miles.	25 meters initial connection.	32 cables, 8 main cables released and re-tensioned each 100 m of column construction.				
Prime Cables	C/C (4.1.2.3)		Deployed from facilities by reels. Final length up to 10 miles.	25 meters initial connection. 200 meters from facility during construction	72 reels at CF-1 and CF-3, 288 cable ends.				
Peripheral Cables	C/C (4.1.2.2)	682,000 kg for each of 2 cables at each quadrant	Deployed by reels. Cable made up of power conductors stepped to accommodate increasing power.	25 meters	8 reels			Safety provisions because of electrical potential between peripheral cables.	
Secondary Tape Reels	C/C (4.1.2.4)	10 kg	Tapes deployed from reels.	200 meters from facility.	844 reels		Lighting. Reels maintain 22 Newton tension.		
Secondary Tape Ends	C/C (4.1.2.4)		Attach tape ends to peripheral cable.	~25 meters from facility.	844 reels		Lighting		
Solar Cell Package	C/C (4.1.3.1)	Max. 48,000 kg	10 x 10 x 8 meters	100 meters	10 per array channel repeated 60 times at each of 2 facilities.		Lighting		
Concentrator Package	C/C (4.1.3.3)	Max. 5,000 kg	100 meter long roll	100 meters	2 per array channel - repeated 120 times at each of 2 facilities		Lighting		
Power Distribution System on SECS	C/C (4.1.4)	Small	Electrical connectors to peripheral cable.	<25 m	2 per array channel	Connector plug engagement.	EVA crewmen. Lighting.	GEO environment.	Requires fine dexterity.
Power Distribution System Conductors	C/C (4.1.4)	63 kg/meter	Conductor cables 17 cm diameter.	Installed along column and extension structure.	4 cables leading to each NPTS				
Auxiliary SPS Equipment	C/C (4.1.5)	6530 kg each	ACS modules.	Vicinity of CF.	24 at each end of ± X column.	Probe and drogue engagement.			
		4000 kg total TBD per unit	I & C modules.	Vicinity of CF.	TBD	Probe and drogue engagement.			
		520,000 kg each (can be broken into smaller units)	Counterweights.	Vicinity of CF.	TBD	Not critical.			
		TBD	Auxiliary equipment mounting provisions.	Vicinity of CF.	~30	Hard mounted to structure.	Provisions for aligning modules.		

Table 3.4.1-2 (Continued)

SPS ELEMENT	SOURCE	FUNCTIONAL CHARACTERISTICS				POSITIONING ACCURACY	SUPPORT REQUIREMENTS	CONSTRAINTS	GRIP CONSIDERATION
		MASS (UNIT/TOTAL)	CONFIGURATION	DISTANCE	PROCESS CYCLES				
Tension Rods	IT (1.1.4)	~20 kg	Small	900 m	Facility - 80 SPS truss - 1260	Locate ends within 1 cm lateral, 50 angular. Insert in nodal drogue fitting.	Lighting		
Beam Builders	IT facility (1.2.1)	40,000 kg (est)	13 meter diameter cylindrical	Capture and place in position for attachment to facility structure.	22	Spot position.	Lighting.		
Solar Cell Blanket Installers and Concentrator Installers	IT facility (1.2.2)	Mount - TED Max. solar cell roll - 7 x 10 ⁶ kg. Max. concentrator roll - 7 x 10 ⁵ kg.	Mount - TED Rolls 650 m long.	300 m	24 mounts 4 SC rolls 8 concentrator rolls	Position mounts for mechanical attachment. Place rolls into mount receptacles.	Lighting.		
Tension Cable Installers	IT facility (1.2.3)	TED	TED	25 m	30	Hold for mechanical attachment to facility structure.	Lighting.		
Power Distribution Harness Installers	IT facility (1.2.4)	~163,000 kg each	TED	Installers return 2600 meters while installing harness cables.	2 at beginning of construction phase and 2 at end.	Hold for mechanical attachment to facility structure.	Lighting.		
Auxiliary Facility Equipment	IT facility (1.2.5)	TED	Propulsion, ACS and GN & C Modules	25 m	~20	Mechanical attachment to facility structure.	Lighting.		
SECS Support Trusses	IT (3.1)	837 kg	10 m triangular x 650 m long	25 m	~1800 total. 28 at one operation, 7 in one bay.	Engage end probe into centroidal fitting.	Lighting maintained throughout facility.		
Transition Structure	IT (3.1.10)	Small	Short 10 meter beams.	25 m	Once at end of SECS construction, <6 beams installed.	Engage end probe into centroidal fitting.			
Auxiliary SPS Equipment	IT (3.1.11)	Assume 7400 kg ea.	ACS modules	Near vicinity of facility structure.	50 spread throughout construction phase.	Probe and drogue engagement.	Lighting.		
		4200 kg total TED per unit.	I & C modules.	Near vicinity of facility structure.	TED	Probe and drogue engagement.	Lighting.		
		TED	Auxiliary equipment mounting provisions.	Near vicinity of facility structure.	~55	Hard mounted to structure.	Provisions for aligning modules.		
Facility Manipulators	BT facility (1.1.4)	TED	~110 meters long	Up to 250 m	6 (each facility)	Hard mounted to structure at preinstalled beam pads.	Lighting.		
		TED	~700 meters long	50 m	2 (each facility)				
FCS Stanchions	BT facility (1.1.4)	~25 kg	Rod with base structure.	10 m	4 (each facility)	Spot position hard mounted to structure.	Lighting.		
Cavity Absorber Shell	BT (2.1.1.1)	~53,000 kg each	20 x 29 m panel section.	100 m	53 (each module)	Hold in spot position for fastening.	Lighting.		
Turbogenerator Sats	BT (2.1.1.3)	~216,400 kg each	Heavy machinery and tanks joined in 20 x 29 x 5 meter package.	25 meter	76 (each module)	Hold in spot position for mechanical fastening.	Lighting.	Could be installed in smaller units but leakage potential increases.	
Bus Bar Harness	BT (2.1.1)	6300 kg each bundle.	Wire harnesses top and bottom of turbogenerator band.	25 meters - all around shell perimeter.	2 harnesses per module.	Spot fastening to shell.			
Radiator Frames	BT (2.1.1.4)	930 kg max. 120 kg min.	10 meter triangular beams, up to 950 meters long.	500 meters from CF	19 beams	Hold in spot position for fastening.			Distribute load over thin members. Beams may have to be gripped at one end.
Radiator Segments	BT (2.1.1.4)	Assumed 500,000 kg each.	Radiator panel ~160 x 730 meters.	500 meters from CF.	12 segments	Hold in spot position for fastening.			
Leak Check and Service Unit	BT (2.1.1.5)	YES (NAK ~4.8 x 10 ⁵ kg for each FCS)	Self contained unit for providing leak check gas and for servicing NAK.	<300 meters (on CF frame)	Depends on method.	Not critical.	EVA crewman to inspect for leakage.	GED environment.	
Solar Concentrator (SC) Support Sate Structure	BT (2.1.2.1)	Estimated 600 kg each in 10 pieces.	Preassembled structure attached to cavity absorber shell.	200 meters	6 pieces	Hold in spot position for fastening.			

Table 3.4.1-2 (Continued)

SPS ELEMENT	SOURCE	FUNCTIONAL CHARACTERISTICS							
		MASS (UNIT/TOTAL)	CONFIGURATION	DISTANCE	PROCESS CYCLES	POSITIONING ACCURACY	SUPPORT REQUIREMENTS	CONSTRAINTS	GRIP CONSIDERATION
SC Construction Modules	BT (2.1.2.2)	Estimated 65,000 kg	15 m diameter module capable of manufacturing 10 m beam out both ends.	Capture and place in spot position.	6	Spot positioning.			Construction module manipulators achieve actual contact and placement.
SC Support Struts and Cross Trusses	BT (2.1.2.3)	Up to 1560 kg	10 meter triangular beams up to 1500 meters long.	Beams replaced in vicinity of construction module.	Each module builds and installs ~5350 meters of beams in 7 pieces.	± 2.5 cm throughout support structures.	Optical aids and accurate measurement of beam lengths.	Measurements made in stable thermal conditions.	
SC Tension Cables	BT (2.1.2.4)	TBD	Up to 2775 meters long.	Attachment within 970 meters of construction module.	24 to 36 cables (per SPS module)	Probe insertion.			
SC Reflector Framework	BT (2.1.2.5)	~220 kg per beam	10 meter triangular beams x 225 meters long	Construction module moved to installation site.	1368 beams installed by 6 construction modules.	Spot position.			Special handling problem because of large flat expanse with attach mechanism close on one side.
Secondary Structure	BT (2.1.2.5)	~5000 kg each	Pop-out structure ~225 m equilateral triangle x 10 meter thick.	Installed in near vicinity to construction module.	762 at each SPS module.	3 point spot positioning and hold for attachment.			
Reflector Facets	BT (2.1.2.6)	~65 kg each	Flat hexagonal material stretched between tension structures at 3 sides.	Installed in near vicinity to construction module.	17,000 (each SPS module)	Probe insertion into steering mechanism.			
Primary Power Bus Trusses	BT (2.1.3.1)	~146 kg each	10 meter triangular beams x 150 m long. Caps are power conductors with lateral elements insulators.	In vicinity of CF frame.	2 (each SPS module)	Butt beam ends onto SC support structure at specific location.	Align prior to fastening.		
Spinal Truss	BT (2.1.3.2)	~330 kg	10 meter triangular beam x 340 meter long. Caps are power conductors with lateral elements being insulators.	~250 meters	Once (per SPS module)	Hold to bus trusses for fastening.			
Auxiliary EPS Equipment	BT (2.1.4.1)	400,000 kg each module.	ACS modules	In vicinity of CF.	TBD	Probe and drogue engagement.	Provisions for aligning modules.		
		TBD	Mounting provisions.	In vicinity of CF.	TBD	Hard mounted to SC support base structure.			
HPTS	BT (2.1.4.2 and 4.2.2)	21 x 10 ⁶ kg	Complete assembled HPTS with rotary transformer assembly.	Capture by SPS system equipment and hold for attachment.	2	Hold for hard attachment.			
Orbit Transfer System	BT (2.1.4.3)	TBD	Ion/chemical propulsion stages.	Docked to SC and PCS structure by use of onboard equipment.	3 (per module)	Engage in mounting equipment.	Mounting provisions pre-installed.		
SPS Modules	BT (4.1.2)	80 x 10 ⁶ kg		Capture and hold modules together for fastening.	3 places	Hold for fastening.			
Spinal Trusses Between PCs	BT (4.1.3)	TBD	10 meter triangular beams	Total span between pair of PCs is ~4000 meters.	3 places	Hold for fastening beam ends together.			
Construction Equipment	C/C Option A	TBD	TBD	Up to 5003 m	2		Assume transport system installed as columns are built.		
Solar Cell Packages	C/C Option A	4,000 to 50,000 kg	10 x 10 meters x up to 8 meters thick.	< 100 meters	10 packages per SECS trough, 300 packages per quadrant.				
Concentrator Rolls	C/C Option A	4,000 to 50,000 kg	100 meter long roll x up to 1.0 meter diameter.	< 100 meters	60 rolls per quadrant.				
Prime Cables	C/C Option A	Small	Ends of small cables moved in preparation for attachment to solar cells.	< 50 meters	33 cable ends per quadrant.	Hold for attachment.	Carry all coded cables along as work proceeds along columns.		
Secondary Tape Reels	C/C Option A	~10 kg each.	Small reels.	< 100 meters	844 reels total. Installed along both sides of columns.	Hold for spot attachment.			
Secondary Tape Attachments to Peripheral Cables	C/C Option A	22 newton pull force at each tape.	Pull on tapes deploy solar cell and concentrator packages.	Up to 14,000 meters.	Depends on how deployment is performed.	Not critical. Items pre-marked and located.			
Automated Construction Equipment	TF Option A	TBD	TBD	< 100 meters	Estimated 36 places.	TBD			

Table 3.4.1-2 (Continued)

SPS ELEMENT	SOURCE	FUNCTIONAL CHARACTERISTICS				POSITIONING ACCURACY	SUPPORT REQUIREMENTS	CONSTRAINTS	CRIP CONSIDERATION
		MASS (UNIT/TOTAL)	CONFIGURATION	DISTANCE	PROCESS CYCLES				
Long-beam SC Construction Equipment	BT Option A	Estimated 6000 kg	Long truss structure.	TED	Once				
Solar Cell Roll Mounts	C/C Option B	Estimated 200 kg each mount.	Mounts to hold solar cell roll and to zipper SC to concentrator.	~25 m	30 pairs per quadrant	Hold for fastening.			
Solar Cell Re-supply Roll	C/C Option B	40,000 kg	100-meter long rolls.	~25 m	~100 per quadrant.	Place in mounts.			
Re-supply Beam Dividers	Planned unscheduled service.	TED	Stack material on rolls installed and material fed out.	< 2 m	A/R	Not critical. Aids in builder receptacle.	IVA crewman.		
Replace/Recharge Battery System	Planned unscheduled service.	TED	TED	< 2 m	A/R	Hold for docking.	Dock equipment to facility maintenance area.		
Service Equipment Propulsion Tanks		TED	TED	< 2 m	A/R		Operation controlled remotely and/or by IVA crewman.		
Re-supply Fastening Device (welders, glue gun, etc)		TED	TED	< 2 m	A/R				
Replace SPS Commodity Modules	Planned unscheduled service.	TED	Compact package on order of 1 m ³ in volume.	TED	A/R	Insert in guides for module insertion.	TED		
Lubrication	Planned/scheduled maintenance.	TED	Lubrication device.	At spot of application.	A/R	Spot position.	Operated by EVA crewman or automated.		
Remove reflector facet layer.	Planned/scheduled maintenance.	~20 kg	Remove top layer of facet material.	TED	100 per day if all replaced in a 2-year period.	Grab small rip tab.		Potentially hot environment. Free-flyer must maintain some distance away.	TED
Helium and NaK System Recharge	Planned/scheduled maintenance.	Service cart (TED)	Cart with large NaK supply tank.	< 25 m hookup distance, < 300 meters on CF frame from LF.	A/R	Not critical.	EVA crewman available.	Environment	
Troubleshooting	Contingencies	TED	Instrumentation Viewing device.	Rear < 5 m	A/R	Requires great dexterity.	EVA crewman or remote control	Environment	
Personnel Rescue	Contingencies	~200 kg	Single person.	Rear	A/R		Facility equipment.		
		TED	Multiple person vehicle.	Within facility.					
Returned Failed Parts to Shop	Contingencies	Estimated 20 - 500 kg.	Mobile/portable construction equipment.	Rear	A/R				
		Estimated 100 - 2000 kg.	SPS operational modules (e.g. subarrays)	TED			Provisions for hand docking.		
On-site Repairs	Contingencies	< 100 kg	Repair kit.	Hands on.	A/R		EVA crewman.	Environment	
		> 200 kg	Replacement part.	Hands on.					
		> 1000 kg	Leak check and service cart.	~25 m					
Extension Structure Beams (structure length: 750 m for C/C, 1 km for TT, 30 m for BT)	C/C MPTS 4.2.1.1, 4.2.1.2, 4.2.1.3, 4.2.2.3, 3.2.1.1, 3.2.1.2, 3.2.1.3, BT MPTS 2.2.7	C/C: 1620 kg (3530 lbs) 25 kg per 100 m TT: 1443 kg (3114 lbs) 23 kg/100 m length BT: 72 kg (159 lbs) 11 kg per 30 m length	Lengths: C/C 66 @ 65 meters, 4 @ 25 meters TT: 30 @ 100 m, 4 @ 40 m, 25 @ 30 m BT: 4 @ 30 m 4 @ 20 m Δ 4.3 m	CF beam fabricator to structure assembly point: 35 to 750 m for C/C, 40 to 1000 m for TT, < 30 m for BT	~70 (C/C) ~60 (TT) ~10 (BT)	< 50 cm	May require additional transporter or several handlers along structure.	Beams must be transported if handler cannot work over specified range (up to 1 km)	Longer beams may require 2 pt. handler.
Electrical Conductors (between joint and SECS)	C/C MPTS 4.2.1.3, 4.2.2.3, TT MPTS 3.2.1.3, BT MPTS	63 kg/meter C/C: 47,250 kg/conductor TT: 63,000 kg/conductor BT: 4,725 kg/conductor	Wire bundle, 750 m long (C/C) 1 km long (TT) 75 m long (BT) 4 conductors, 17 cm dia each.	Joint to SECS: up to 1 km.	4	< 2 cm	May require transporter or several handlers at and between end points.	Conductors must be transported between attach points if handler cannot reach.	Reel(s)
Ball Joint	C/C MPTS 4.2.2.1		11 m dia cylinder	Transporter to end of extension structure < 20 m.	1	< 2 cm	Handler can be attached to transporter or to extension structure.		

Table 3.4.1-2 (Concluded)

SPS ELEMENT	SOURCE	FUNCTIONAL CHARACTERISTICS							
		MASS (UNIT/TOTAL)	CONFIGURATION	DISTANCE	PROCESS CYCLES	POSITIONING ACCURACY	SUPPORT REQUIREMENTS	CONSTRAINTS	GRIP CONSIDERATION
Support Arm Beams	C/C MPTS 4.2.2.2 TT MPTS 3.2.2.7 BT MPTS 2.2.6	C/C: 1500 kg (3300 lbs) TT: 940 kg (2063 lbs) BT: 240 kg (520 lbs)	Lengths: Δ 5.5 m C/C - 2 @ 165 m 50 @ 65 m, 4 @ 150 m TT - same as C/C BT - 4 @ 65 m, 4 @ 25 m 10 @ 30 m, 4.3 m Δ	Transporter to support arm assembly point; reach of 25 to 200 m	$\sim$ 60 (C/C) $\sim$ 60 (TT) $\sim$ 20 (BT)	< 25 cm	Handler can be attached to transporter joint or extension structure.	Beams may require additional transport from fabricator (distance to BT can be up to 1 km); handler may require transport.	Longer beams may require handling at both ends.
Frames	C/C MPTS 4.2.3.1 TT MPTS 3.2.3.1 BT MPTS 2.2.1.1	140/9240 kg (308/20328 lb)	65 m x 130 m rectangle Δ 4.3 m	Transporter to MPTS: 130 to 500 m	66			Frames may require additional transport if handler has limited reach, or handler could be transported. Secondary structures may require additional transport if handler has limited reach or handler could be transported.	
Secondary Structures	C/C MPTS 4.2.3.2 TT MPTS 3.2.3.2 BT MPTS 2.2.1.2	1200/115200 kg (2640/2534400 lb)	130 m equilateral triangle x 3 m each - beam structure Δ 4.3 m	Transporter to top of frames - max. 500 m	95				
Radial Cables (between MPTS rings)	C/C MPTS: 4.2.3.1 TT MPTS: 3.2.3.1 BT MPTS: 2.2.1.1		Small diameter cables, lengths - 36 @ 150 m each 144 @ 175 m each	Transporter to frames; frame-to-frame distance (ring to ring) $\sim$ 130 m	180			Cables may require additional transport if handler has limited reach or handler could be transported.	Attached at both ends to frames, transported on reels.
Subarrays (onto secondary structures)	C/C MPTS 4.2.4.2 TT MPTS 3.2.4.2 BT MPTS 2.2.2.2	500/570500 kg (440/3455760 lbs)	10 x 10 x 0.25 m each	Transporter to secondary structure; max. reach req'd $\sim$ 500 m	7854			Subarrays may require additional transport if handler has limited reach, or handler can be transported.	
Electronics Packages Interconnect (electronic conductors)	C/C MPTS 4.2.5.1 TT MPTS 3.2.5.1 BT MPTS 2.2.3.1		Small diameter, 10 m lengths each.	Transporter to bottom of subarrays: 10 to 500 m	$\sim$ 7000			Interconnects or handler require additional transport to cover 1 km dia antenna; poss. interference problems within secondary structure.	
RF Lines	C/C MPTS 4.2.5.1 TT MPTS 3.2.5.2 BT MPTS 2.2.3.2		Small diameter, lengths between 10 and 500 m	10 to 500 m	$\sim$ 700		Handler may require transport between attachment points.	Interference problems with secondary structure.	Cable ends.
Switch Gears	C/C MPTS 4.2.6.1 TT MPTS 3.2.6.1 BT MPTS 2.2.4.1	2000/33000 kg (4400/70400 lbs)	TBD	Transporter to attach points, 70 to 500 m.	16		Handler may require transport between attachment points.	Interference problems within secondary structure unless attached within structure prior to transport.	Cable ends.
Electrical Conductors (between joint bus and switch gears)	C/C MPTS 4.2.6.2 TT MPTS 3.2.6.2 BT MPTS 2.2.4.2	15.75 kg/m 4 @ 9450 kg each 4 @ 7675 kg each 4 @ 6100 kg each 4 @ 4725 kg each	Lengths: 4 @ 500 m 4 @ 500 m, 4 @ 400 m 4 @ 300 m 8.5 cm dia. each	Transporter to attach pts, up to 500 m, between attach points.	16		Same as above.	Same as above.	Cable ends.
Electrical Conductors (between switch gears and distribution points)	C/C MPTS 4.2.6.3 TT MPTS 3.2.6.3 BT MPTS 2.2.4.3	Same as above.	Lengths: 4 @ 500 m 4 @ 400 m, 4 @ 300 m 4 @ 200 m + 1000 @ 100 m 8.5 cm dia each	Between attach points 100 to 500 m	$\sim$ 1000		Same as above.	Same as above.	Cable ends.
Electrical Conductors (8 distribution points between subarrays)	C/C MPTS 4.2.6.4 TT MPTS 3.2.6.4 BT MPTS 2.2.4.4		10 m lengths	Between attach points - 10 m	$\sim$ 7000		Handler may require transport to cover full 1 km dia antenna.	Same as above.	
Support Beams - Counterweight Cone	C/C MPTS 4.2.7.1	54 kg ea (108 lbs) 6480 kg (14256 lbs)	150 m long each 5.5 m Δ	150 m, between attach points	120		Handler may require mobility to build entire structure.	Interference with structure as it is built.	Multiple handlers may be required for the 150 m beams.
Counterweight (including CNGs)	C/C MPTS 4.2.7.2	10^6 kg	50 m x 50 m x 50 m	$\sim$ 100 m	1 (unless transported in pieces)		Probably will be assembled at site.	Mass must be reduced by handling pieces only.	
Computer	C/C MPTS 4.2.8.1 TT MPTS 3.2.8.1		TBD	$\sim$ 70 m from transporter to attach point in MPTS secondary structure	1			Interference with secondary structure, counterweight support structure, joint.	
Wiring (between computer, reference subarrays and drive system)	C/C MPTS 4.2.8.2 TT MPTS 3.2.8.2		Lengths: 3 @ 75 m C/C 2 @ 200 m TT 2 @ 300 m BT plus 1 @ 625 m (C/C) 1 @ 100 (TT)	Between attach points: 75 to 625 m between subarrays, up to 500 m	8 lines			Cable and structure avoidance, handler may require transport between attachment points and between subarrays.	
Drive System and Power Transfer Mechanism (rotary joint)	TT MPTS 3.2.2.2, 3.2.2.3		TBD	Between elevation and azimuth joints $\sim$ 100 m	Several steps.				Handler attached to extension structure, joint or MPTS.
Electrical Conductors (rotary joint buses)	TT MPTS 3.2.2.4 3.2.2.5 3.2.2.6	8 @ 63 kg/feet: 4 @ 1575 kg each 4 @ 6300 kg each 16 @ 15.75 kg/m 394 kg each	Small dia lengths of 25, 100 and 25 meters 8 @ 17 cm dia, 16 @ 0.5 cm dia.	Between attachment points 25 - 100 m	Several steps.				Same as above.
Rotary Transformer Assembly (RTA)	BT MPTS 2.2.8.1		20 m dia.	Between attachment points - 20 m	1				Handler attached to MPTS, or FF.
Power Conversion Equipment and Filter	BT MPTS 2.2.8.2			Within extension structure - from transporter - $\sim$ 25 m	Several steps.			Interference with extension structure.	Same as above.
Structure Beams - Rotary Joint	TT MPTS 3.2.2.7	$\sim$ 23 kg (49.5 lbs) ea $\sim$ 2320 kg (4950 lbs)	4.3 m Δ , lengths 50 - 150 m	$\sim$ 100 m	$\sim$ 100			May require transport to site (beams or handler).	

Table 3.4.1-3 Generic Process Summary - Align

SPS ELEMENT	SOURCE	FUNCTIONAL CHARACTERISTICS					
		DESCRIPTION	PROCESS CYCLES	ACCURACY	SUPPORT REQUIREMENTS	CONSTRAINTS	EXIST
Auxiliary Equipment	C/C (4.1.5) TT facility (1.2.5)	Align ACS and propulsion thrust vectors by adjusting mounting provisions	C/C - 48 TT facility - TBD TT - 65	TBD	Measurement of SECS and structures relative to auxiliary equipment		
	TT (3.1.11)	Alignment navigation sensors by adjusting mounting provisions	TBD	TBD			
Facility Beams	BT facility (1.1.4)	Align beams prior to welding. Facility provides jig for cavity construction.	8 places (each facility)	TBD	Optical measurements		
PCS Stanchions	BT facility (1.1.4)	Align prior to hard fastening. Stanchions are jig points for cavity absorber.	4 (each facility)	TBD	Optical measurements		
SC Construction Module/Beams	BT (2.1.2.2)	Align beam attachment inside SC construction module to assure module equidistance apart	4 places	2 sec in two planes	Optical aids and accurate measurement of beam lengths. Recommend alignment stations set up on SC base structure.	More accurate to adjust struts after construction is started, to ± 2.5 cm	
Primary Power Bus Trusses	BT (2.1.3.1)	Align power truss as relative to PCS aperture centerline.	2 (each SPS module)	TBD	Optical aids and accurate measurement of beam lengths. Recommend alignment stations set up on SC base structure.		
Auxiliary Equipment	BT (2.1.4.1)	Align ACS thrust vectors and sensors by adjusting mounting provisions	TBD	TBD	Measurement of PCS and SC subsystems alignment. Lighting	Facility in thermal stability	
Beam Builders	C/C facility (1.1)	Gross alignment of beam builders prior to fastening in place on facility structure	6	2.5 cm at 100 m beam span	Lighting. Optical measurement	Facility in thermal stability	
Extension Structure	C/C HPTS 4.2.1.1 TT HPTS 3.2.1.1 BT HPTS 2.2.7	Align beams of structure as each section is assembled	~20 (C/C) ~20 (TT) ~3 (BT)	± 2 cm	Lighting, monitoring, alignment measurement		Align each section against existing sections
Support Arm Beams	C/C HPTS 4.2.1.3 TT HPTS 3.2.1.3 BT HPTS 2.2.6	Same as above	~20 (C/C) ~20 (TT) ~5 (BT)	± 2 cm	Same as above		Same as above
Support Beams - Counterweight Cone	C/C HPTS 4.2.7.1	Same as above	20 - 50 times	± 5 cm	Same as above		Same as above
On-site Repair	Contingencies	Align construction equipment, when applicable, after repair	A/R	A/R	EVA crewman	Environment	

Table 3.4.1-4 Generic Process Summary - Fasten

SPS ELEMENT	SOURCE	FUNCTIONAL CHARACTERISTICS			
		MATERIALS	JOINT	PROCESS CYCLES	CONSTRAINTS
Prime Cables	C/C (4.1.3.3)		Cable ends attached to SECS rings	264 connections. Max of 10 at one operation.	Difficult to automate. GEO environment constraints on EVA crewmen.
Power Distribution System on SECS	C/C (4.1.4)	Concentrator conductive material connected to peripheral cable conductors	Feed out conductor from concentrator joined to pig-tail connector feeding into peripheral cable.	240 total connections	Electrical potential across alternate concentrator peaks, when deployed.
Power Distribution System Conductors	C/C (4.1.4)	Conductor cables	Connector plugs for 17 cm diameter cable segments of TBD length. Attach cable to structure periodically.	4 cables leading to each MPTS.	
Auxiliary Equipment Mounts	C/C (4.1.5)	TBD	Hard mounted to structure - mechanical, weld, etc.	~30	
Beam Builder	TT facility (1.2.1) C/C facility (1.1)		Mechanical fastening to facility structure	33 - TT 6 - per each C/C CF	
Solar Cell and Concentrator Installer Mounts	TT facility (1.2.2)		Mechanical fastening to facility structure	24	
Tension Cable Installers	TT facility (1.2.3)		Mechanical fastening to facility structure	30	
Power Distribution Harness Installers	TT facility (1.2.4)		Mechanical fastening to facility structure	4	
Auxiliary Facility Equipment	TT facility (1.2.5)		Mechanical fastening to facility structure	~20	
SECS Support Trusses	TT facility (3.1)	TBD	Centroidal fittings	~2416 total 14 in one bay at one operation at 5 day intervals.	
Facility Beams and Tension Rods	C/C facility (1.1.4 & 3.3) TT facility (1.1.4)	Any	Centroidal joint with probe and drogue fitting. Requires external torque mechanism for hard mate.	C/C: 30 - beam ends 24 - rod ends TT: 236 - beam 144 - rods	Only work base may be beam previously installed but not yet structurally stable.
Main/Prime Cable Reel Assemblies	C/C facility (3.0)	TBD	Reel base plate mechanically attached to facility structure.	104 reels	
Peripheral Cable Reel Assemblies	C/C facility (3.0)	TBD	Reel base plate mechanically attached to facility structure.	4 reels	
Secondary Tape Reel Assemblies	C/C (4.1.2.4)	TBD	Reel base plate mechanically attached to column structure.	840 reels	
Secondary Tape Ends		Kevlar	Attach tape ends to peripheral cables	840 places	
Solar Cell Packages	C/C (4.1.3.1)		Attach packages to C/C column. Interconnect 10 x 10 m panels	10 per array channel - repeated 60 times at each of 2 facilities. 9 connections at each of 1200 rows of panels (max case) - repeated 60 times at each of 2 facilities.	
Concentrator Packages	C/C (4.1.3.1)		Attach concentrator rolls to C/C column. Attach concentrator material (conductor system) to solar cell electrical conductor.	2 per array channel - repeated 120 times at each of 2 facilities. (Automated system desirable - rolled solar cells could be attached easier but roll mass would be great).	
Solar Cells Panels and Concentrators (SECS)	C/C (4.1.3.2)	Preinstalled rings hooked over tapes	Rings hooked over tapes	5400 rings at each of 2 facilities. Max of 360 at a 200 meter increment.	Difficult to automate. GEO environment constraints on EVA crewmen.
Prime Cables	C/C Option A		Cable ends attached to SECS rings	264 total connections. Max of 10 connections at one operation.	Difficult to automate. GEO environment constraints on EVA crewmen.
Secondary Tape Reels	C/C Option A		Reel base plate mechanically joined to column structure	840 total reels	
Power Distribution Connectors to Peripheral Cables	C/C Option A	Concentrator conductive material	SECS connector joined to peripheral cable pig-tail connector	60 connections each quadrant	

Table 3.4.1-4 (Continued)

SPS ELEMENT	SOURCE	FUNCTIONAL CHARACTERISTICS			
		MATERIALS	JOINT	PROCESS CYCLES	CONSTRAINTS
Turbogenerator Sets	BT (2.1.1.3)	TBD	Mechanical fastening to shell panels. Connect helium lines.	16 sets installed (each module). Estimated 6 mechanical joints and 2 helium line joints.	More connections if greater breakdown in units.
Bus Bar Harness	BT (2.1.1)	Aluminum cable bundles	Fastened to shell. 24 electrical junctions each bundle.	Two harnesses per module. 16 mechanical joints each. 24 electrical joints each	
Radiator Frames	BT (2.1.1.4)	TBD	Frame ends butted and welded.	24 beam connections	
Radiator Segments	BT (2.1.1.4)	TBD	Join to frames and between segments.	12 segments	
Solar Concentrator (SC) Support Base Structure	BT (2.1.2.1)	TBD	Structure joined to cavity shell.	12 pieces (each module)	
SC Construction Modules	BT (2.1.2.2)	TBD	Fasten internal beam being manufactured to support base structure	6 places	Alignment prior to fastening is necessary.
SC Support Struts and Cross Trusses	BT (2.1.2.3)	TBD	Butt beam ends	~7 joints each construction module	Beam length adjustment needed.
SC Tension Cables	BT (2.1.2.4)	TBD	Probe insertion and rotary force for tightening joint	24 to 36 cables	
SC Reflector Framework	BT (2.1.2.5)	TBD	TBD	1368 beams installed (each SPS module)	
Secondary Structure	BT (2.1.2.5)	TBD	TBD. Each structure attached at three places.	762 structures (each SPS module)	
Reflector Facets	BT (2.1.2.6)	TBD	Facet probe inserted into steering mechanism receptacle.	17,000 (each SPS module)	Steering mechanism must be installed in secondary structure prior to installation.
Reflector Control Circuitry	BT (2.1.2.7)	Electrical connectors	Electrical plug connections at: 17,000 facets, ~1400 secondary structure joints, and ~30 primary structure joints.	~18,400 connections (each module)	All control and power distribution wiring installed on structure at manufacture. Potential interference with secondary structure.
Secondary Tapes joined to Peripheral Cables	C/C Option A		Join secondary tapes to peripheral cables to maintain tension on SECS	211 each quadrant	Difficult to automate. GEO environment. No support structure, therefore free-flyer is applicable.
Resupply Beam Builders	Planned Unscheduled Service	TBD	Latch roll in receptacle and feed material strip into machine slot.	A/R	
Replace/Recharge Battery Systems	Planned unscheduled service	TBD	Battery-lead junction opening and closing	A/R	
Service Equipment Propulsion Tanks	Planned unscheduled service	Liquid propellant	Connect propellant fill and drain lines.	A/R	Remote control of flow initiation and stop. Servicing done in explosion-safe area.
Resupply Fastening Device	Planned unscheduled service	Weld material glue, etc.	Insert canister into device and cycle operation	A/R	Small devices reloaded in IVA environment. EVA required to service large equipment.
Replace SPS Commodity Modules	Planned unscheduled service	Module attach fittings	Standard attachment mechanism designed for use with remote controlled equipment	A/R	
Lubrication	Planned/scheduled maintenance	Lubricant dispenser	Attach dispenser to fitting	TBD	Could be eliminated by incorporating in an automatic system
Solar Cell and Concentrator Material Attachment	TT (3.1.6 & 3.1.7)	Solar cells on flexible substrate. Concentrator is flexible thin plastic. Both attached at the edges to the truss structure and both "zippered" together to provide electrical contact.	TBD	24 places	Make initial connections by manual means. Automated thereafter except for maintenance or to start new rolls of materials.
Power Distribution System	TT (3.1.8)	Conductor cables at 31.3 kg/water	Feed out conductor from concentrators joined to conductor cables	8 electrical connectors at each end of SECS	Cable installation to structure is automated
Transition Structure (SECS to MPTS)	TT (3.1.10)	TBD	Centroidal fittings	At end of SECS construction. ~6 beams installed.	Part of facility structure used to maintain positive contact between SECS and MPTS structures.
Auxiliary Equipment Mounts	TT (3.1.11)	TBD	Hard mounted to structure - mechanical weld, etc.	~55	

Table 3.4.1-4 (Continued)

SPS ELEMENT	SOURCE	FUNCTIONAL CHARACTERISTICS			
		MATERIALS	JOINT	PROCESS CYCLES	CONSTRAINTS
Helium and NaK System Recharge	Planned/scheduled maintenance	Connectors TBD	Connect service lines to SPS system	TBD	Manual system justified because of few occurrences
Troubleshooting	Contingencies	Test instrumentation	Connect instrumentation to SPS test points	A/R	Requires caution and dexterity because of potential hazards in power circuits.
On-site Repairs	Contingencies	Parts and repair kit Leak Repair Kit Cable Splice Kit Conductor repair kit Module Attach Fittings	Remove and replace flexible material Repair leak Splice cable break Repair conductor break Miscellaneous parts replacement Replace SPS line-replaceable-unit (LRU)	A/R	Requires stable base. Requires on-site judgment and dexterous task activities. Requires stable base/attachment. LRU exchange could be automated.
Solar Cell Roll Mounts	C/C Option B		Install mounts for solar cell rolls to column structure.	60 pairs in each quadrant	
Switch Gears	C/C MPTS 4.2.6.1 TT MPTS 3.2.6.1 BT MPTS 2.2.4.1	Any	Contact latches	16 switch gears, 2 to 4 latches each	Built into bottom of secondary structures (where applicable, 16 places)
Electrical Conductors (between joint bus and switch gears)	C/C MPTS 4.2.6.2 TT MPTS 3.2.6.2 BT MPTS 2.2.4.2	Any	Quick disconnect concept incorporating automatic latching, or may require external force/torque mechanism	16	Successive fastening tasks up to 100 meters apart (or conductors can be attached to switch gears prior to placement of switch gears within antenna substructure; then connections only required at joint bus)
Electrical Conductors (between switch gears and distribution pts)	C/C MPTS 4.2.6.3 TT MPTS 3.2.6.3 BT MPTS 2.2.4.3	Any	Same as above.	~1000	Fastening required at 1000 different locations, over whole surface (back surface) of MPTS.
Electrical Conductors (9 distribution points between subarrays)	C/C MPTS 4.2.6.4 TT MPTS 3.2.6.4 BT MPTS 2.2.4.4	Any	Same as above	~7000	Fastening required @ 10 meter increments over whole surface (back surface) of MPTS.
Support Beams - Counterweight Cone	C/C MPTS 4.2.7.1	Any	Centroidal joint with probes and drogue fitting, requires external torque mechanism for hard mate.	120 beams	
Counterweight (including CMGs)	C/C MPTS 4.2.7.2		Weld counterweight pieces; CMG assembly latched to counterweight	1 counterweight assy - several pieces (massive)	
Computer	C/C MPTS 4.2.8.1 TT MPTS 3.2.8.1		Latched to structure in base of MPTS substructure	1	
Wiring (between computer, reference subarrays and drive system)	C/C MPTS 4.2.8.2 TT MPTS 3.2.8.2	Any	Quick disconnect concept incorporating automatic latching, or may require external force/torque mechanism	8 lines	Sixteen connections required over distances up to 1 km, if accomplished separately.
Drive System and Power Transfer Mechanism (rotary joint)	TT MPTS 3.2.2.2, 3.2.2.3		TBD	Several (<10)	
Electrical Conductors (rotary joint buses)	TT MPTS 3.2.2.4, 3.2.2.5, 3.2.2.6		Quick disconnect concept incorporating automatic latching, or may require external force/torque mechanism.		
Rotary Transformer Assembly	BT MPTS 2.2.8.1		Multiple centroidal with probes and drogue fitting. Requires external torque mechanism for hard mate.	1	
Power Conversion Equipment and Filter	BT MPTS 2.2.8.2		Latched to extension structure - multiple points	Several (<10)	
Structure Beams - Rotary Joint	TT MPTS 3.2.2.1		Centroidal joint with probe and drogue fitting. Requires external torque mechanism for hard mate	~100 beams	

Table 3.4.1-4 (Concluded)

SPS ELEMENT	SOURCE	FUNCTIONAL CHARACTERISTICS			
		MATERIALS	JOINT	PROCESS CYCLES	CONSTRAINTS
Primary Power Bus Trusses	BT (2.1.3.1)	TBD	Autt weld to SC support structure base.	2 (each SPS module)	Requires alignment prior to fastening
Spinal Truss	BT (2.1.3.2)	TBD	Weld to primary power bus trusses.	1 (each SPS module)	
Bus Bar Connections	BT (2.1.3.3)	Electrical conductors connected to power truss	Mechanical connections	6 (each SPS module)	
Auxiliary Equipment Mounts	BT (2.1.4.1)	TBD	Hard mounted to structure	TBD	Once in LEO Once in GEO
MPTS	BT (2.1.4.2 & 4.2.1)	TBD	Temporary mechanical attachment at six places between MPTS face and bottom of SC structure on one module. Permanent mechanical attachment of rotary transformer assembly to edge of SC structure	Once in LEO Once in GEO	
Orbit Transfer System	BT (2.1.4.3)	TBD	Mechanical and electrical connections to preinstalled SPS interface	3 each module	
SPS Modules	BT (4.1.2)	SC structures	Mechanical connections of SPS module edges	3 places	Difficult to automate. GEO environment constraints on EVA crewmen.
Spinal Trusses between PCSs	BT (4.1.3)	TBD	Beams butted and hard fastened	3 spans installed	
Solar Cell Packages	C/C Option A	Solar cells on flexible substrate - all in panel form	Attached to column adapter frame at bottom of trough. Rings at each panel are hooked on secondary tapes.	300 packages installed each quadrant. 1800 ring attachments each quadrant.	
Concentrator Rolls	C/C Option A	Aluminized flexible material	Roll attached to column fittings. Material automatically attached to solar cell material. Periodic edge rings attached to secondary	60 rolls installed each quadrant. 900 ring attachments each quadrant.	Difficult to automate. GEO environment constraints on EVA crewmen.
Extension Structure Beams	C/C MPTS 4.2.1.1, 4.2.1.2 TT MPTS 3.2.1.1, 3.2.1.2 BT MPTS 2.2.7	Any	Centroidal joint with probe and drogue fitting. Requires external torque mechanism for hard mate.	~70 (C/C) ~60 (TT) ~10 (BT)	
Electrical Conductor - between Joint and SECS	C/C MPTS 4.2.1.3, 4.2.2.3 TT MPTS 3.2.1.3 BT MPTS	Any	Quick disconnect concept. May require external force/torque mechanism.	4	
Ball Joint	C/C MPTS 4.2.2.1		Weld	1 joint (<10 weld points)	May require jig.
Support Arm Beams	C/C MPTS 4.2.2.2 TT MPTS 3.2.2.7 BT MPTS 2.2.6	Any	Centroidal joint with probe and drogue fitting. Requires external torque mechanism for hard mate.	~60 (C/C) ~60 (TT) ~20 (BT)	
Frames	C/C MPTS 4.2.3.1 TT MPTS 3.2.3.1 BT MPTS 2.2.1.1	Any	Same as above, plus factor that angle between frame ends is not 0° (different fittings)	66 frames (attached @ corners)	
Secondary Structures	C/C MPTS 4.2.3.2 TT MPTS 3.2.3.2 BT MPTS 2.2.1.2		Three-point attachment at base to top of frame structures	96 secondary structures (3 attachment tasks each)	Interference with secondary structure, if fastening mechanism moves among all subarrays.
Radial Cables (between MPTS rings-frames)	C/C MPTS 4.2.3.1 TT MPTS 3.2.3.1 BT MPTS 2.2.1.1		Cable attached to frame at one end, through adjustable reel at other end. Tension mechanism required at reel end.	180 cables	
Subarrays	C/C MPTS 4.2.4.2 TT MPTS 3.2.4.2 BT MPTS 2.2.2.2		Three-point attachment to top of secondary structures.	7854 subarrays	
Electronic Packages Interconnects	C/C MPTS 4.2.5.1 TT MPTS 3.2.5.1 BT MPTS 2.2.3.1	All wave-guides or coax cables	Quick disconnect concept incorporating automatic latching.	~7000	Lines may require attachment to structure along length for support.
RF Lines	C/C MPTS 4.2.5.2 TT MPTS 3.2.5.2 BT MPTS 2.2.3.2		Lines attached at center of antenna, other ends go to 700 separate points - quick disconnect concept	~700	
Facility Beams	BT facility (1.1.4)	TBD	Hard fasten beam ends; e.g., weld	6 beams (each module)	
Facility Manipulators	BT facility (1.1.4)	TBD	Mechanical attachment to preinstalled pads.	8	Assume helium lines brought outside cavity for ease of joining
PCS Stanchions	BT facility (1.1.4)	TBD	Mechanical attachment to preinstalled pads	4	
Cavity Absorber Shell	BT (2.1.1.1)	Titanium outer skin. Insulation - 25 cm of aluminum-silica. Inner walls -	Panel edges welded together. Helium lines connected by welding.	~195 helium line connections (assume 2 connections for each of 93 panels). ~10,000 meters of panel edges welded.	

Table 3.4.1-5 Generic Process Summary - Align

SPS ELEMENT	SOURCE	FUNCTIONAL CHARACTERISTICS		
		DESCRIPTION	PROCESS CYCLES	CONSTRAINTS
Facility Tension Rods	C/C facility (1.1.4) TT facility (1.1.4)	Adjust tension rods to bring facility longitudinal beams into alignment.	C/C - 12 tension rods, TT - 144 tension rods. Repeated adjustments in pairs until longitudinal beams are aligned.	Force must be reacted off one of beams in system being adjusted to prevent distorting system alignment. Requires thermal stability for jig accuracy.
Facility Beam End Fittings (Adjustable)	C/C facility (1.1.4) TT facility (1.1.4)	Adjust beam end fittings to align diagonal beams	C/C - 12 places; TT - 36 places. Repeated adjustments as required to align facility framework.	
Facilities	C/C (3.3)	Adjust beam end fittings to make 6 facilities mutually perpendicular	18 adjustments.	
Main/Prime Cables	C/C (4.1.2.5)	Maintain cables at 3000 Newton tension	Release and retension cables each 100 m of column construction. 144 times, up to 96 cables involved towards end of construction.	
Peripheral Cables	C/C (4.1.2.5)	Maintain cables at 3000 Newton tension	Release and retension cable each 100 m of construction. 144 times.	
Final Alignment	C/C (5.2)	Adjust main, prime, and peripheral cables as required to establish perpendicularity of columns and make SECS flat.	As required	Cable reels must have individual takeup controls. Requires thermal stability for accurate alignment.
SECS Support Trusses	TT (3.1)	Adjust beam end fittings to align diagonal beam plane	504 adjustment points. Repeated as required.	
SECS Tension Rods	TT (3.1.5)	Adjust tension rods to bring SECS longitudinal beams into alignment.	1260 adjustment points. Repeated as required.	
SC Tension Cables	BT (2.1.2.4)	Adjust tension cables to stiffen structure.	24 to 36 adjustments.	
Spinal Trusses between PCSs	BT (4.1.3)	Adjust spinal truss length to make the axis of each of the solar concentrators parallel.	As required over the 3 spans.	Alignment monitoring difficult because of great distance involved.
Frames	C/C MPTS 4.2.3.1 TT MPTS 3.2.3.1 BT MPTS 2.2.1.1	Top surface of frames adjusted via tension in radial cables. Iterative process; means required to determine if rings (made up of frames) are at same level.	54 outer frames adjusted to 12 frames of first concentric ring.	Adjusting mechanism may require transport among radial cables between rings. Process may have to be repeated several times over all rings prior to placement of secondary structures.

Table 3.4.1-6 Generic Process Summary - Monitor

SPS ELEMENT	SOURCE	FUNCTIONAL CHARACTERISTICS				CEW FUNCTION
		PARAMETER	FREQUENCY	SUPPORT REQUIREMENTS	CONSTRAINTS	
• Structure Alignment - Extension Structure - Support Arms - Counterweight Support Structure	C/C HPTS 4.2.1.1, 4.2.1.2, 4.2.1.3 TT HPTS 3.2.1.1, 3.2.1.2, 3.2.1.3 BT HPTS 2.2.6, 2.2.7 C/C HPTS 4.2.7.1	Beams parallel or @ right angles, angle measurement	As each section is assembled, up to 20 processes	Lighting, direct or remote visual contact		No
• Frame Adjustment, Installation	C/C HPTS 4.2.3.1 TT HPTS 3.2.3.1 BT HPTS 2.2.1.1	Frame-to-frame attachment; distance between concentric ring frames (~150 m); top beam of frames parallel and in same plane (monitoring required by task)	Continuous during ring construction	Same as above		No
• Secondary Structure	C/C HPTS 4.2.3.2 TT HPTS 3.2.3.2 BT HPTS 2.2.1.2	Attachment of secondary structures to frame surfaces (monitor process)	Continuous during placement of 95 secondary structure	Same as above		No
• Subarrays - Installation	C/C HPTS 4.2.4.2 TT HPTS 3.2.4.2 BT HPTS 2.2.2.2	Attachment of subarrays to secondary structures (monitor process)	Continuous during placement of 7854 subarrays	Same as above		No
• Ball Joint - Installation	C/C HPTS 4.2.2.1	Attachment of ball joint to extension structure	Once, continuous during joint installation	Same as above		No
• Electrical Conductors - Between Joint & SECS - Between Joint Bus & Switch Gears - Between Computer Reference Subarrays and Drive System - Rotary Joint Buses	C/C HPTS 4.2.1.3 TT HPTS 3.2.1.3 BT HPTS C/C HPTS 4.2.6.2 TT HPTS 3.2.6.2 BT HPTS 2.2.4.2 C/C HPTS 4.2.8.2 TT HPTS 3.2.8.2 TT HPTS 3.2.2.4, 3.2.2.5, 3.2.2.6	Conductor cable attachment (monitoring required by task)	4 16 8 24	Same as above		No
• Electronics Packages Interconnections	C/C HPTS 4.2.5.1 TT HPTS 3.2.5.1 BT HPTS 2.2.3.1	Fastening process (monitoring required by task or monitor automatic process)	~7000 - continuous during task	Same as above		No
• RF Lines	C/C HPTS 4.2.5.2 TT HPTS 3.2.5.2 BT HPTS 2.2.3.2	Attachment task (monitoring required by task)	~700 continuous during task	Same as above		No
• Switch Gears	C/C HPTS 4.2.6.1 TT HPTS 3.2.6.1 BT HPTS 2.2.4.1	Switch gear attachment to structure (monitoring required by task)	Continuous during task, 16 times	Lighting, direct or remote visual contact		No
• Electrical Conductors - Between Switch Gears and Distribution Points - Between Subarray & Distribution Points	C/C HPTS 4.2.6.3 TT HPTS 3.2.6.3 BT HPTS 2.2.4.3 C/C HPTS 4.2.6.4 TT HPTS 3.2.6.4 BT HPTS 2.2.4.4	Conductor attachment (monitoring either required by task, or monitor automatic process)	1000 times, continuous 7000 times, continuous	Same as above		No
• Counterweight - Assembly/Installation	C/C HPTS 4.2.7.2	Monitoring required by task	Once	Same as above		No
• Computer - Installation	C/C HPTS 4.2.8.1 TT HPTS 3.2.8.1	Same as above	Once	Same as above		No
• Drive System and Power Transfer Mechanism - Installation	TT HPTS 3.2.2.2, 3.2.2.3	Same as above	Once	Same as above		No
• RTA Installation	BT HPTS 2.2.8.1	Same as above	Once	Same as above		No
• Power Conversion Equipment & Filter Installation	BT HPTS 2.2.8.2	Same as above	Once	Same as above		No
• Radial Cable Installation	C/C HPTS 4.2.3.1 TT HPTS 3.2.3.1 BT HPTS 2.2.1.1	Same as above	Continuous during installation of 180 cables	Same as above		No
Helium and NaK Recharge	Planned/scheduled maintenance	Mechanical and/or electrical	A/R	Leak surveillance		No
Troubleshooting	Contingencies	Physical observation	A/R	Optical system controlled remotely or EVA crewman	Environment	No
On-site Repairs	Contingencies	Physical observation	A/R	Assessment of damage, evaluation of fix requirements	Requires judgment and decisions based on observa	No

Table 3.4.1-6 (Concluded)

SPS ELEMENT	SOURCE	FUNCTIONAL CHARACTERISTICS				C&W FUNCTION
		PARAMETER	FREQUENCY	SUPPORT REQUIREMENTS	CONSTRAINTS	
Facility Beam Alignment	C/C facility (1.1.4) TT facility (1.1.4)	Physical alignment of beams	C/C: 30 angles aligned TT: ~350 angles aligned	EVA crewmen to install and operate alignment jigs or optical devices. Lighting aids.		No
Facility Docking to Hub	C/C facilities (3.3)	Physical alignment and engagement of facilities to hub	15 beam ends	Video viewing or EVA crewmen	GEO environmental constraints on EVA crewmen	No
Facility Alignment	C/C facilities (3.3)	Assure 6 facilities are mutually perpendicular	Once for initial alignment. Continuous for column alignments.	Alignment device to aid in aligning facilities at start and to maintain columns in perpendicularity.	GEO environmental constraints on EVA crewmen	No
SECS Flatness	C/C (5.2)	Physical measurement of SECS for flatness	As required	Sighting aids. Takeup provisions in prime cable reels.		No
Assembly General Surveillance	All	Physical mating or placement activities • Beams • Cables • Reels • Solar Cell Packages • Concentrator Rolls • Tension Rods • Power Distribution Connectors & Conductors • Auxiliary Equipment	Many	EVA crewmen or video capabilities for wide angle and zoom. Display area in IMF. Lighting at site.	GEO environment limitations for EVA.	C&W for all automated systems
SPS Module Alignment	BT (4.1.3)	Assure all four SPS modules are paralleled	Once	Adjust spinal truss length. Optical measurement of SPS module alignments.		No
Recharge Battery Systems	Planned unscheduled service	Electrical	A/R	Automatic shutdown capability. Crewman in vicinity.		Yes
Service Equipment Propulsion Tanks	Planned unscheduled service	Mechanical and/or electrical	A/R	Redundant safety features. Leak surveillance.	Isolated explosion safe area required	Yes

Table 3.4.1-7 Generic Process - Checkout

SPS ELEMENT	SOURCE	FUNCTIONAL CHARACTERISTICS			
		PARAMETER	PROCESS CYCLES	SUPPORT REQUIREMENTS	CONSTRAINTS
Control and Display Station	C/C (5.0) TT (4.0) BT (5.0)	Activate subsystems and verify operations • ACS • Power Generation • I&C • Computers • CMGs	Per system		
Leak Check	BT (2.1.1.5)	Verify no leaks in helium and NaK piping at four PCSs	2 systems in each of 4 modules		
Recharge Battery Systems	Planned unscheduled service	Verify system charge and serviceability	A/R	Instrumentation and verification function (crewman or computer)	
Troubleshooting	Contingencies	Instrumentation tests on system to isolate malfunction	A/R	Automated checkout functions minimizes manned involvement.	
On-site Repairs	Contingencies	Instrumentation tests on system to verify repair	A/R	Automated checkout functions minimizes manned involvement.	
Electrical Continuity (between Joint and Distribution Points)	C/C MPTS 4.2.2.3, 4.2.6.2, 4.2.6.3 TT MPTS 3.2.2.3, 3.2.6.2, 3.2.6.3 BT MPTS 2.2.4.2, 2.2.4.3	Existence of current	~1000		Conductor path checked is 1 km long
Electrical Continuity (between Subarrays)	C/C MPTS 4.2.5.1 TT MPTS 3.2.5.1 BT MPTS 2.2.3.1	Existence of current	~785 (every group of 10 subarrays)		Checked paths are 100 m long over whole 1 km dia antenna
Pointing Control System Continuity (between Drive System and Reference Subarrays)	C/C MPTS 4.2.8.2 TT MPTS 3.2.8.2	Noninfinite resistance	8 lines		Checked paths are ~700 meters long

Table 3.4.1-8 Other Construction Operations

TASKS	PROCESS INVOLVED							SPS APPLICABILITY		
	TRANSPORT	HANDLE	ALIGN	FASTEN	ADJUST	MONITOR	CHECKOUT	C/C	TT	BT
<u>PLANNED UNSCHEDULED SERVICE</u>										
Resupply Beam Builders	X	X		X				X	X	X
Replace/Recharge Battery Systems		X		X		X	X		TBD	
Service Equipment Propulsion Tanks		X		X		X			TBD	
Resupply Fastening Device (Weld, Glue, etc)	X	X		X					TBD	
Replace SPS Commodity Modules (ACS Tanks)	X	X		X				X	X	X
<u>PLANNED/SCHEDULED MAINTENANCE</u>										
Lubrication	X	X		X				X	X	X
Remove Reflector Facet Layer	X	X								X
Recharge NaK System	X	X		X		X				X
Recharge Helium System	X	X		X		X				X
<u>CONTINGENCIES</u>										
Troubleshooting										
• Visual Inspection	X	X				X			A/R	
• Instrument Checks (on-site)	X	X		X			X		A/R	
Personnel Rescue										
• Single Personal ECLSS	X	X							TBD	
• Multiple Personnel ECLSS	X	X							TBD	
Repairs										
• On-site										
- SPS Damages										
• Material Rip	X	X		X		X		X	X	X
• System Leak	X	X		X		X				X
• Cable Break	X	X		X		X		X	X	X
• Conductor Break	X	X		X		X	X	X	X	X
- Component Replacement (LRU)	X	X		X			X	X	X	X
- Fixed-base Construction Equipment (e.g., beam builder)	X	X	X	X		X	X	X	X	X
• Return to Shop										
- Mobile/Portable Equipment	X	X							TBD	
- Modules (with SRU Components)	X	X							TBD	

3.4.2 Combined Generic Requirements

The separate generic process requirements tables were summarized and combined into one table (Table 3.4.2-1) which facilitated analysis of the SPS element functional requirements across processes. In this way, requirements commonality and quantitative trends could be more easily recognized, and potential areas where common equipment might be adaptable to more than one element or process could be identified.

The combined table was utilized as an analytic tool to establish the general types of OCSE (in qualitative terms) which would be required. The more detailed data contained in the separate generic process tables were utilized as required to quantify requirements. Figures 3.4.2-1, 3.4.2-2 and 3.4.2-3 depict some representative SPS data in quantitative terms (unit mass, transport distance and handling distance respectively, as a function of frequency of occurrence). Although there is a high degree of scatter evident in the data (due to the diversity of elements involved in SPS construction), some limited assessments can be made. Figures 3.4.2-1 and 3.4.2-3, for example, tend to suggest which group of high frequency elements might be accommodated by automated systems, and that the group of less frequently occurring items be more directly controlled. Figure 3.4.2-2 shows that element transport distances are dependent to some degree on the particular SPS concept, and the corresponding proposed locations of construction and logistics facilities.

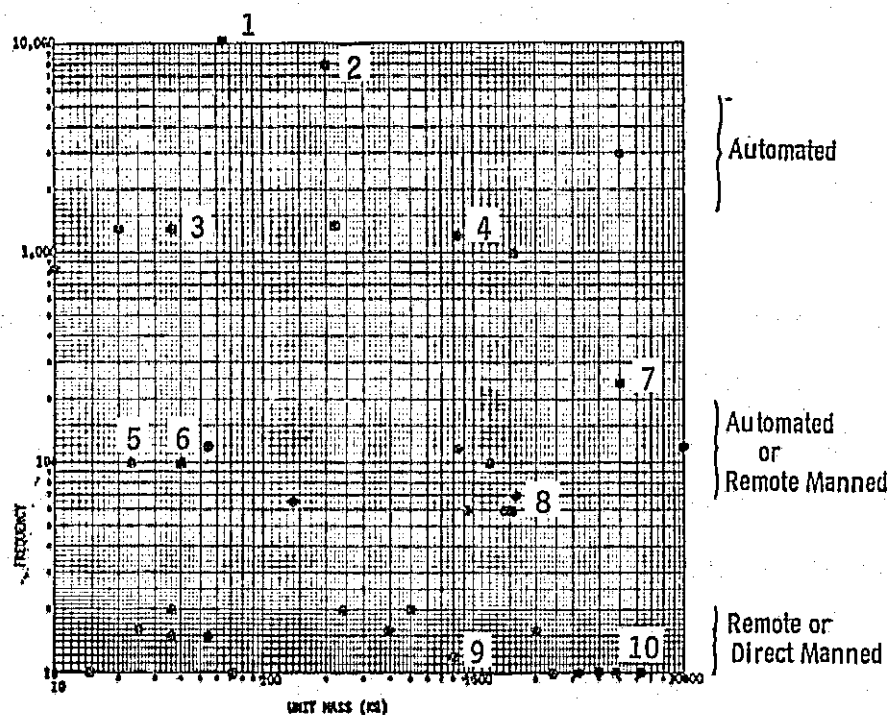


Figure 3.4.2-1 Element Frequency Vs Unit Mass

KEY FOR NUMBERED EXAMPLES:

- 1 Reflector Facets (Boeing Thermal)
- 2 Subarrays, MPTS
- 3 Column Beams (Column/Cable)
- 4 SECS Support Trusses (Truss Type)
- 5 Rotary Joint Structure Beams (Truss Type)
- 6 Cable Reels (Column/Cable)
- 7 Concentrator Material (Column/Cable)
- 8 Extension Structure Beams (Column/Cable, Truss Type)
- 9 Solar Concentrator Support Structure (Boeing Thermal)
- 10 Busbar Harness (Boeing Thermal)

NOTE: Several SPS elements exist with masses $>10^3$ kg and frequencies of occurrence <10 .

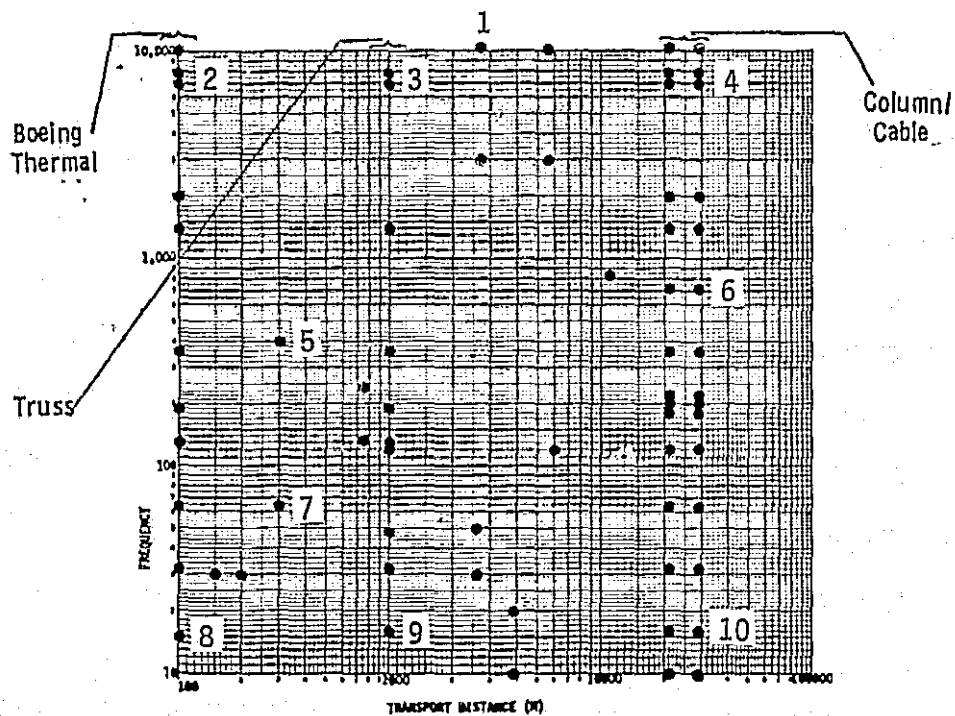


Figure 3.4.2-2 Element Frequency Vs Transport Distance

KEY FOR NUMBERED EXAMPLES:

- 1 Reflector Facets (Boeing Thermal)
- 2 Subarrays, MPTS (Boeing Thermal)
- 3 Subarrays, MPTS (Truss Type)
- 4 Subarrays, MPTS (Column/Cable)
- 5 Cavity Absorber Shell Panels (Boeing Thermal)
- 6 Solar Cell Rolls (Column/Cable)
- 7 Column Beams (Column/Cable)
- 8 Facility Beams (Column/Cable)
- 9 Switch Gears, MPTS (Truss Type)
- 10 Switch Gears, MPTS (Column/Cable)

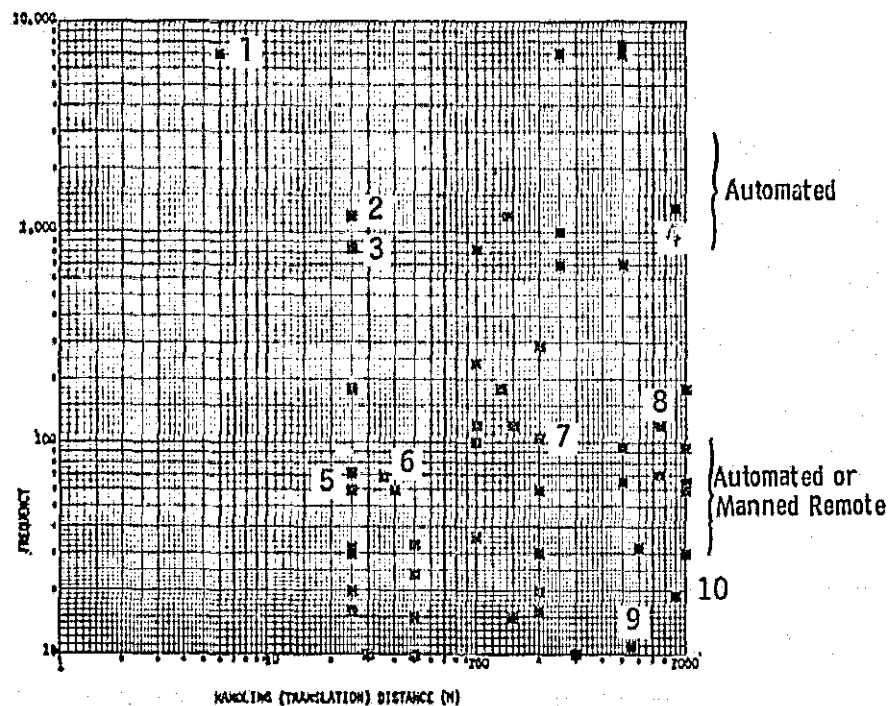


Figure 3.4.2-3 Element Frequency Vs Handling Distance

KEY FOR NUMBERED EXAMPLES:

- 1 Electrical Conductors, MPTS Subarrays
- 2 SECS Support Trusses (Truss Type)
- 3 Secondary Tape Ends (Column/Cable)
- 4 Tension Rods (Truss Type)
- 5 Turbogenerator Sets (Boeing Thermal)
- 6 MPTS Frames
- 7 Main/Prime Cable Reels (Column/Cable)
- 8 Secondary Structure, MPTS
- 9 Radiator Segments (Boeing Thermal)
- 10 Radiator Frame Structure (Boeing Thermal)

Table 3.4.2-1 Combined Generic Requirements

SPS ELEMENT	MASS (UNIT/TOTAL)	ELEMENT CHARACTERISTICS		TRANSPORT		GENERAL HANDLING	
		CONFIGURATION	PROCESS CYCLES	DISTANCE	ATTACHMENT CONSIDERATIONS	DISTANCE	CONSIDERATIONS
Facility Beams	36 kg each (C/C) 837 kg each (TT) 215 kg each (BT)	2.45 m triangle x 110 m long 10 m triangle x 650 m long (TT) 8 m sq beam x 125 m	15 (C/C) 118 (TT) 6 (BT)	50-100 m (C/C) 50-1300 m (TT)	Access thru facility framework, spread loads.	70 m (C/C) 50-300 m (TT) 125 m	Nodal drop Accuracy: 1 m, 50 m
Column Hub Beams	10 to 40 kg each	2.45 m triangle x 5 to 112 m long	31	200 m	Access thru facility framework, spread loads.	100 m	Nodal drop Accuracy: 1 m, 50 m
Secondary Tape Reels	10 kg each 2400 kg max pkg mass	TBD	1 ea 2400 kg package to 2 facilities; 1 ea 1800 kg package to 2 facilities	LF to CF 13 miles FF 18 miles attached	Packaged on 2400 kg or 1800 kg reels	200 m from facility	22 Newtons automatic tied
Peripheral Cables	682,000 kg each	Reel	4 each to 2 facilities	LF to CF 13 miles FF 18 miles attached	Packages 188 m ³ ea	25 m	Cables are ductors - consideration
Solar Cell Packages (C/C)	Max pkg mass 40,000 kg	Max package 10 x 10 x 8 meters	120 pkgs	LF to CF 13 miles FF 18 miles attached	Packaged in groups; packages progressively smaller	100 m	10 per array 50 packages of 2 facilities
Concentrator Material (C/C)	Max pkg mass 5000 kg	100 meter long rolls	240 rolls	LF to CF 13 miles FF 18 miles attached	Packaging in groups	100 m	2 per array repeated 10 each of facilities
Solar Cell Blanket Installers (TT)	Total - 7 x 106 kg plus mount	Rolls 650 m long, 14 ft diameter for all material	4 rolls 8 mounts	LF to installation point 3900 m max	Mount TBD	300 m	Position place roll mounts
Construction Equipment (C/C & TT Facility & BT)	TBD	TBD					
Concentrator Installers (TT)	Mount TBD; Total material 7 x 105 kg	Rolls 650 m long	8 rolls 16 mounts	LF to installation point 3900 m max		300 m	Position place roll mounts
Tension Cable Installers (TT)	TBD	TBD	30	LF to installation point 2600 m max		25 m	Hold for attachment facility structure
Power Distribution Harness Installers (TT)	163,000 kg each	Includes 4 12 cm dia cables per installer	4 (2 @ ea end wall)	LF to installation point 2600 m max	2 installed at beginning of construction; 2 at end of construction	2600 m	Hold for attachment facility structure
Auxiliary Facility Equipment (TT) & (C/C)	TBD	Propulsion, ACS, GN&C Modules	20	LF to installation point 3900 m max	Need provision for aligning modules	25 m	Hold for attachment facility structure
Auxiliary SPS Equipment - ACS Modules	355,000 kg total; 7000 kg ea		50	Installed in facility up to 2600 m	Propellant hazard, if damaged	Near facility structure	Probe & dr
- TAC Modules	4000 kg ea		TBD				Probe & dr
- Mounting Provisions	total		54				Hard mount structure, alignment

nts

PORT ATTACHMENT CONSIDERATIONS	GENERIC PROCESSES		ALIGN	FASTEN	ADJUST	MONITOR	CHECKOUT	REMARKS
	HANDLE	CONSTRANTS/ SUPPORT REQTS.						
DISTANCE			TASK DESCRIPTION	TASK DESCRIPTION	TASK DESCRIPTION	PARAMETER	PARAMETER	
thru facility work, spread	70 m (C/C) 10-300 m (TT) 125 m	Nodal drogue fitting Accuracy: 1 cm lateral, 5° angular	BT: Align beams prior to welding; facility provides jig for cavity construction 8 places per facility.	Centroidal joint with probe and drogues; external torque required for hard mate (C/C): 15 beams - both ends, 136 beam ends (TT), 12 beam ends (BT) - welded	Adjust beam length @ 12 places; repeat as required to align facility C/C = 12 places TT = 38 places	Alignment - 30 angles; jigs or optical devices required (EVA installed) TT: 35 angles		Grip @ both ends, or over large area. Only work base may be preceding beam, not structurally stable.
thru facility work, spread	100 m	Nodal drogue fitting Accuracy: 1 cm lateral, 5° angular	NA					Grip @ both ends, or over large area. Only work base may be preceding beam, not structurally stable.
ed on 2400 kg 0 kg reels	200 m from facility	22 Newtons tension automatically applied	NA	Reel base plate mechanically attached to structure, 840 places				
es 188 m³ ea	25 m	Cables are power conductors - safety considerations	NA	Reel base plate mechanically attached to structure	Release/retension cables each 100 m, 144 times			
ed in groups; es progress-smaller	100 m	10 per array channel 60 packages @ each of 2 facilities	NA	Attach pkgs to column, interconnect 10 x 10 m panels; 9 connections @ each of 1200 rows of panels (x 120)				Automated fastening system desirable; but roll mass would be great.
ing in groups	100 m	2 per array channel repeated 120 times @ each of 2 facilities	NA	Attach rolls to column, attach concentrator material to solar cell conductors Rings hooked over tapes; 9000 rings/facility - max 600 rings/200 m				DIFFICULT to automate; GEO EVA constraints
TBD	300 m	Position mounts; place rolls in mounts	NA	Mechanically fasten mounts to structure				Supply SC roll 14 times Each roll is then 500,000 kg
	300 m	Position mounts; place rolls in mounts	NA	Mechanically fasten mounts to structure				
	25 m	Hold for mechanical attachment to facility structure	NA	Mechanically fasten mounts to structure				
alled at be- g of construc- 2 at end of uction	2600 m	Hold for mechanical attachment to facility structure	NA	Mechanically fasten mounts to structure				
rovision for ng modules	25 m	Hold for mechanical attachment to facility structure	Align by adjusting mounting provisions; measure SECS/structure positions	Mechanically fasten to facility structure				
lant hazard, aged	Near facility structure	Probe & drogue Probe & drogue Hard mounted to structure, requires alignment	Align by adjusting mounting provisions; measure SECS/structure positions	Hard mounted to structure ~30 (C/C) ~55 (TT)				

Table 3.4.2-1 (Continued)

SPS ELEMENT	ELEMENT CHARACTERISTICS			TRANSPORT		GENERIC PRO	
	MASS (UNIT/TOTAL)	CONFIGURATION	PROCESS CYCLES	DISTANCE	ATTACHMENT CONSIDERATIONS	DISTANCE	HANDLE CONSTRAINTS SUPPORT REQUIREMENTS
Tension Rods (C/C)	5 kg	Small-diameter filament with probe end fitting and adjustment (e.g., turn-buckle)	12/facility; plus 864 0 4 facilities; and 431 0 2 facilities for SPS			141 m	Accuracy: 1 cm lateral, 5° angular; Insert in node; drogue fitting
Column Beams (C/C)	36 kg each	2.45 m triangular x 100 m long	867 0 4 facilities 435 0 2 facilities			~70 m	Accuracy: 1 cm lateral, 5° angular; Insert in node; drogue fitting
Facilities (Dock to Hub)	1200 kg + base facilities Est. 100,000 kg	100 m triangular x 200 m long	5 once for initial alignment, continuous, for column alignment			Docking placement	Facility ACS provides gross placement; simultaneous; Insert 3 probes; 1 cm lateral, 1°
Main/Prime Cable Reels (C/C)	40 kg		104 reels 0 CF-1 & CF-3			200 m	
Main Cables		Deployed from facilities by reels; final length up to 12.7 miles	32 cables			25 m Initial connection	
Prime Cables		Deployed from facilities by reels; final lengths up to 10 miles	72 reels 0 CF-1 & CF-3 288 cable ends			25 m Initial connection; 200 m from facility during construction	
Secondary Tape Ends			840			25 m from facility	Attach tape end to peripheral cable
Power Distribution System on SECS	Small	Electrical connector to peripheral cable	2 per array channel			<25 m	Connector plug; engagement; may require fine dexterity (EVA crewman)
Power Distribution System Conductors	63 kg/meter TBD length	Cables - 17 cm dia	4 cables to each MPTS				Installed along umbilical and MPTS mission structure
Tension Rods (TT)	20 kg	Small	Facility - 80 SPS truss - 1260			900 m	Insert in node; drogue fitting; Accuracy - 1 cm lateral; 5° angular
Beam Builders (TT facility) (C/C facility)	40,000 kg est. 15,000 kg ea	13 meter dia, cylindrical 5 m dia x 15 m	32 (TT) 6 per C/C CF			50 m	Capture place in position for attachment to facility structure
SECS Support Trusses	837 kg	10 m triangular x 650 m long	1203 total 28 in one operation; 7 in one bay			25 m	Engage end probe to centroidal fitting
Transition Structure (SECS to MPTS)	Small	Short 10 m beams	Once 0 end of SECS construction (6 beams installed)			25 m	Engage end probe to centroidal fitting
Solar Cell and Concentrator Material Attachment (TT)			24 places				

PORT ATTACHMENT OPERATIONS	GENERIC PROCESSES		TASK DESCRIPTION	FASTEN TASK DESCRIPTION	ADJUST TASK DESCRIPTION	MONITOR PARAMETER	CHECKOUT PARAMETER	REMARKS
	HANDLE	ALIGN						
	DISTANCE	CONSTRAINTS/SUPPORT REQTS.						
	141 m	Accuracy: 1 cm lateral, 50 angular Insert in nodal drogue fitting		Probe and drogue; requires external torque for hard mate	Adjust to bring facility longitudinal beams into alignment; repeated in pairs as required			Only work base during facility construction may be preceeding beam, not structurally stable. Adjustment force must be reacted off beam to prevent distortion--requires thermal stability.
	~70 m	Accuracy: 1 cm lateral, 50 angular Insert in nodal drogue fitting						Grip beam @ both ends or over large area; may require 2 handlers.
	Docking place-ment	Facility ACS provides gross placement; simultaneously insert 3 probes 1 cm lateral, 1 min			Adjust beam end fittings to make 6 facilities mutually perpendicular; 18 adjustments	Physical alignment & engagement of facilities; video or EVA (GEO constraints) 15 beam ends		May require EVA assistance; need to grip all 3 points of facility to prevent bending loads.
	200 m			Reel base plate mechanically attached to facility structure				
	25 m initial connection			Maintain cables @ 3000 Newtons tension	8 main cables released & retensioned as 100m of column constructed; 144 times			
	25 m initial connection; 200 m from facility during construction			Cable ends attached to SECS rings, 264 connections max 20 @ one operation	Maintain cables @ 3000 Newtons tension. Release/retension as 100m of construction; 144 times, up to 96 cables			Difficult to automate; GEO environment constraints on EVA.
	25 m from facility	Attach tape ends to peripheral cable		Attach 840 places				
	~25 m	Connector plug engagement; may require fine dexterity (EVA crewman)		Concentrator conductive material connected to peripheral cable conductors; 240 total connections				Electrical potential across alternate concentrator peaks when deployed.
		Installed along column and MPTS extension structure		Connector plugs; attach cable to structure periodically				
	900 m	Insert in nodal drogue fitting; Accuracy - 1 cm lateral; 50 angular			1260 adjustment points, repeated as required--adjust rods to bring SECS longitudinal beams into alignment			
	50 m	Capture place in position for attachment to facility structure	C/C: Gross alignment prior to fastening; 2.5 cm @ 100 m span, requires optical measurement and thermal stability	Mechanically fasten to facility structure 32 cycles				
	25 m	Engage end probe into centroidal fitting		Centroidal fittings, 2416 total; 14 in one bay @ one operation @ 5 day intervals	Adjust beam end fittings to align diagonal beam plane 50 adjust pts, repeat as required			
	25 m	Engage end probe into centroidal fitting		Centroidal fittings; part of facility structure; use to maintain positive contact between SECS and MPTS				
				Solar cells on flexible substrate. Concentrator is flexible thin plastic. Both attached @ edges to truss structure and zippered together (electrical contact)				Initial connections manual; automate thereafter except for maintenance or to start new rolls.

Table 3.4.2-1 (Continued)

SPS ELEMENT	ELEMENT CHARACTERISTICS			TRANSPORT			GENERIC PROCESS	
	MASS (UNIT/TOTAL)	CONFIGURATION	PROCESS CYCLES	DISTANCE	ATTACHMENT CONSIDERATIONS	DISTANCE	HANDLE CONSTRAINTS/SUPPORT REQTS	
Power Distribution System (IT)	31.3 kg/m	Conductor cables	8 connectors at each end of SECS					
Final Alignment Main/Prime/Peripheral Cables								
• Beams, Cables, Reels • Solar Cell Packages • Concentrator Rolls • Tension Rods • Power Distribution Connectors & Conductors • Auxiliary Equipment (C/C, IT, BT)		Display area in IMF; lighting at sites	Many					
Control and Display Station (C/C, BT, IT)								
PCS Stanchions	25 kg	Rod with base structure	4 per facility	Up to 300 m		10 m	Spot position--hard mounted to structure	
Cavity Absorber Shell	53,000 kg each	20 x 29 m panel sections	98 per module	Up to 300 m	Could be transported in larger packages	100 m	Hold in spot position for fastening	
Turbogenerator Sets	236,400 kg each	Heavy machinery and tanks in 20 x 29 x 5 m package	16 per module	Up to 300 m	Could be transported in smaller units	25 m	Hold in position for fastening	
SC Framework Secondary Structures	~5000 kg each	Popout structure deploys to 225 m equilateral triangle x 10 meter thick	762 per module	CF to installation site ~5600 m max attached 2700 m FF		Small, near construction module	Hold for 3 point attachment	
Reflector Facets	~65 kg each	Flat hexagon stretched between tension structure on 3 sides	17,000 per module	CF to installation site ~5600 m attached 2700 m FF		Near construction module	Probe insertion into steering mechanism	
MPTS	21 x 10 ⁶ kg	Complete antenna (1 km dia) with rotary transformer assembly	2 (1 in LEO 1 in GEO)	TBD miles	Stationkeep, capture by manipulator from SC structure		Capture by SPS system test equipment and hold for attachment	
Spinal Trusses Between PCSs	TBD	10 meter triangular beams	3 spans	4000 m per span		~4000 m	Hold for fastening near ends	
Facility Manipulator		100 meters long 700 meters long	6/facility 2/facility			Up to 350 m; 60 m	Hard mounted to structure @ preinstalled beam pads	
Busbar Harness	6300 kg per bundle	Wire harness top & bottom of turbogenerator band	2 per module			25 m - all around shell	Spot fastening to shell	
Radiator Frames	120 to 930 kg	10 m triangular beams, up to 950 m long	19 beams			900 m from CF	Hold in spot position for fastening	
Radiator Segments	500,000 kg each	Panel 180 x 730 meters	12 segments			550 m CF	Hold in spot position for fastening	

GENERIC PROCESSES								
CENT ATIONS	HANDLE		ALIGN	FASTEN	ADJUST	MONITOR	CHECKOUT	REMARKS
	DISTANCE	CONSTRAINTS/ SUPPORT REQHTS.	TASK DESCRIPTION	TASK DESCRIPTION	TASK DESCRIPTION	PARAMETER	PARAMETER	
				Feed out conductor from concentrators joined to conductor cable				Cable installation to structure is automated
					Adjust main, prime & peripheral cables as required to establish perpendicularity of columns & flatness of SECS	Physical measurement of SECS alignment sighting aids required		Cable reels requiring individual takeup controls; thermal stability required.
						Assembly general surveillance; EVA crewman or video with wide angle & zoom		CAN for all automated systems; GEO environment limitations for EVA.
							Activate systems & verify operations	ACS IAC CMGs Power Computers
	10 m	Spot position--hard mounted to structure	Align prior to hard mounting (optical measurement); stanchions are Jig points for cavity absorber	Mechanical attachment to preinstalled pads	NA	NA	NA	
transported packages	100 m	Hold in spot position for fastening	NA	Titanium skin, insulation - 25 cm AL-Si; inner walls - columbium; Weld panel edges (10,000 m) and helium lines (196)	NA	NA	NA	Assume helium lines brought outside cavity for ease of joining.
transported units	25 m	Hold in position for fastening	NA	Mechanical fastening to shell panels, connect helium lines (8 connections)				Leakage potential increased if package is transported in pieces.
	Small, near construction module	Hold for 3 point attachment	NA	3 point attachment				
	Near construction module	Probe insertion into steering mechanism		Probe inserted into steering mechanism receptacle				Large flat surface with attach mechanism close on one side - visibility problem.
capture from re		Capture by SPS system equipment and hold for attachment	NA	Temporary attachment (LEO) at 6 pts between HPTS face & bottom of SC; permanent attachment (GEO) of RTA to edge of SC				
	4000 m	Hold for fastening beam ends	NA	Beams butted and hard fastened	Adjust truss length to make SC axes parallel			Adjustment monitoring difficult because of great distances involved
	Up to 250 m; 50 m	Hard mounted to structure & preinstalled beam pads	NA	Mechanical attachment to preinstalled pads				
	25 m - all around shell	Spot fastening to shell	NA	AL cables, 24 electrical functions per bundle, 16 mechanical joints each				
	900 m from CF	Hold in spot position for fastening	NA	Frames ends butted and welded - 24 connections				Distribute load over skin members; beam may be handled at one end.
	550 m CF	Hold in spot position for fastening	NA	Join to frames and between segments				

Table 3.4.2-1 (Continued)

SPS ELEMENT	ELEMENT CHARACTERISTICS			TRANSPORT		GENERIC PROCESS	
	MASS (UNIT/TOTAL)	CONFIGURATION	PROCESS CYCLES	DISTANCE	ATTACHMENT CONSIDERATIONS	DISTANCE	CONSTRAINTS/ATT SUPPORT REQUIREMENTS
Leak Check and Service Unit	TBD (NaK 4.8 x 10 ⁶ kg for each PCS)	Self-contained, provides leak check gas and NaK servicing				<300 m (on CF frames)	
Solar Concentrator (SC) Support Base Structure	800 kg each in 12 pcs.	Preassembled structure attached to cavity absorber shell	6 places			300 m	Hold in spot positioning for fastening
SC Construction Modules	65,000 kg	15 m dia module which manufactures 10 m beams out both ends	6				Capture and place in spot position
SC Support Struts and Cross-Trusses	Up to 1560 kg	10 m triangular beams up to 1600 m long	~5350 m of beams in 7 pcs - per module			Beams emplaced in vicinity of construction module	±2.5 cm thruout in port structure, measurement aids required
SC Tension Cables	TBD	Up to 2775 meters long	24 to 36 per SPS module			Attachment within 970 m of module	Probe insertion
SC Reflector Framework	220 kg per beam	10 meter triangular x 225 m long	1368 beams 6 construction modules			Construction module moved to installation site	Spot position
Primary Power Bus Trusses	~146 kg ea	10 meter triangular x 150 m long. Caps are power conductors with lateral elements insulators.	2 per SPS module			In vicinity of CF frame	Butt beam ends on SC support structure at specific location
Spinal Truss	330 kg	10 meter triangular x 340 m long. Caps are conductors, lateral elements are insulators.	Once per SPS module			~250 m	Hold to bus trusses for fastening
Orbit Transfer System	TBD	Ion/chemical propulsion stages	3 per module				Docked to SC and by use of onboard equipment
SPS Modules	80 x 10 ⁶ kg total		3 places				Capture and hold modules together for fastening
Reflector Control Circuitry			18,400; probable reduction to ~1500				
Bus Bar Connections			6 per SPS module.				

GENERIC PROCESSES								REMARKS
ATTACHMENT DERIVATIONS	HANDLE		ALIGN	FASTEN	ADJUST	MONITOR	CHECKOUT	
	DISTANCE	CONSTRAINTS/ SUPPORT REQTS.	TASK DESCRIPTION	TASK DESCRIPTION	TASK DESCRIPTION	PARAMETER	PARAMETER	
	<300 m (on CF frames)						Verify no leaks at 4 PCSs (2 systems in ea) EVA inspection	
	300 m	Hold in spot position for fastening		Structure joined to cavity shell (12 pcs for module)				
		Capture and place in spot position	Align beam attachment within module to assure modules are equidistant 2 sec in 2 planes, require measurement aids and alignment stations on SC structure	Fasten internal beam being manufactured to support base structure	More accurate to adjust struts after construction is started, to ± 2.5 cm			Module manipulators achieve actual contact and placement.
	Beams emplaced in vicinity of construction module	± 2.5 cm thruout support structure, measurement aids required	NA	Butt beam ends ~7 joints per module	Beam length adjustment required			
	Attachment within 970 m of module	Probe insertion	NA	Probe insertion and rotary force for tightening joint	Adjust cables to stiffen structure			
	Construction module moved to installation site	Spot position	NA	TBD, 1368 beams per SPS module				
	In vicinity of CF frame	Butt beam ends onto SC support structure at specific location	Align required, trusses relative to PCS aperture centerline, measurement aids and alignment stations on SC structure required	Butt weld to SC support structure base				
	~250 m	Hold to bus trusses for fastening	NA	Weld to primary power bus trusses				
		Docked to SC and PCS by use of onboard equipment		Mechanical and electrical connections to preinstalled SPS interface				
		Capture and hold modules together for fastening	Assure all 4 modules are paralleled; adjust spinal truss length, optical measurement	Mechanical connection of module edges		Module alignment		
				Electrical plug connections at: 17,000 facets, 1400 secondary structure joints A 30 primary structure joints				All control & power distribution wiring installed @ manufacture; potential interference in secondary structure
				Electrical conductors connected (mechanically) to power truss				

Table 3.4.2-1 (Continued)

SPS ELEMENT	ELEMENT CHARACTERISTICS			TRANSPORT			GENERIC PRO	
	MASS UNIT/TOTAL	CONFIGURATION	PROCESS CYCLES	DISTANCE	ATTACHMENT CONSIDERATIONS	DISTANCE	HANDLING CONSTRAINTS	SUPPORT REQUIREMENTS
Electrical Conductors (between Joint Bus and Switch Gears)	8 kg/m 8 @ 4000 kg 8 @ 3200 kg 8 @ 2400 kg 8 @ 4800 kg	6 cm dia (C/C & TT); 8 @ 500 m 8 @ 400 m 8 @ 300 m 8 @ 600 m BT (11 cm dia)	32 per MPTS	Same as above	Transportable on reels	Up to 600 m; CF to MPTS; 100-1500 m	May require transport between points and tasks	
Electrical Conductors (between Switch Gears and Distribution Points)	15.75 kg/m 4 @ 7875 kg 4 @ 6300 kg 4 @ 4725 kg 4 @ 3150 kg 1000 @ 1575 kg	8.5 cm dia; 4 @ 500 m 4 @ 400 m 4 @ 300 m 4 @ 200 m 1000 @ 100 m	~1000 per MPTS	Same as above	Transportable on reels	100 to 500 m; CF to MPTS; 100-1500 m	May require transport between points and tasks	
Electrical Conductors & Distribution Points between Sub-arrays	Small	Small diameter, 10 m lengths	~7000 per MPTS	Same as above		10 m; CF to MPTS; 100-1500 m	Handler may require transport between attach tasks	
Support Beams - Counterweight Cone	54/6480 kg (119/14256 lbs)	5.5 m triangular, 150 m long each	120 per MPTS	CF to MPTS ~750 m		150 m between attach points	Handler requires mobility to structure	
Counterweight (including CMGs)	106 kg	50 x 50 x 50 m	1	LF to MPTS 13 m FF 18 m attach	Transported in pieces	~100 m	Assembled at	
Pointing Computer	TBD, small	Rectilinear	1	C/C: LF to MPTS 13 m FF 18 m attached TT: CF to MPTS, 1 km		70 m, transporter to attach point		
Pointing System Wiring (between computer, 7 reference subarrays and drive system)	TBD	Small diameter, 3 @ 75 m 2 @ 200 m 2 @ 300 m (both C/C and TT) plus 1 @ 625 m for C/C, 1 @ 100 m for TT	8 lines per MPTS	Same as above	Transportable on reels	Between attach pts, 75 to 625 m between subarrays, up to 500 m	Handler may require transport between attach points between subarrays	
Drive System and Power Transfer Mechanism (in rotary joint)	TBD	TBD	1 per MPTS (several pieces)	CF to joint - 1 km		Between azimuth and elevation joints ~100 m	Handler attach extension structure joint or MPTS	
Electrical Conductors (rotary joint buses)	63 kg/m 4 @ 1575 kg 4 @ 6300 kg 16 @ 15.75 kg/m - 394 kg ea	8 @ 17 cm dia, 16 @ 8.5 cm dia lengths of 25 m (16) 100 m (4) 25 m (4)	24 per MPTS	CF to joint - 1 km	Transportable on reels	Between attach pts, 25 to 100 m	Handler attach extension structure joint or MPTS	
Rotary Transformer Assembly (RTA)	TBD	30 m long x 20 m dia	1	CF to joint, <100 m		Between attach pts, 20 m	Handler attach MPTS, or FF	
Power Conversion Equipment and Filter	TBD	TBD	1 (several pieces)	CF to joint, <100 m		Within extension structure from transporter <25 m	Handler attach MPTS, or FF	
Extension Structure Beams	C/C: 1600 kg (36 kg/100 m) TT: 1443 kg (23 kg/100 m) BT: 72 kg (11 kg/30 m)	Each 4.3 m triangle, lengths: C/C: 66 @ 65 m, 4 @ 35 m TT: 30 @ 100 m, 4 @ 40 m, 25 @ 130 m BT: 4 @ 30 m, 4 @ 20 m	70 per MPTS (C/C) 60 per MPTS (TT) 10 for BT MPTS	NA (see Handle)	NA	CF beam fabricator to structure; assy pt: C/C: 35 to 750 m; TT: 40 to 1000 m; BT: 30 m	Handler may require transport as structure is built; use several	

GENERIC PROCESSES								
BY ACCOMPLISHMENT OPERATIONS	HANDLE		ALIGN		FASTEN		CHECKOUT	
	DISTANCE	CONSTRAINTS/ SUPPORT REQS.	TASK DESCRIPTION	TASK DESCRIPTION	TASK DESCRIPTION	PARAMETER	PARAMETER	REMARKS
table on	Up to 600 m; CF to MPTS 100-1500 m	May require trans- port between attach points and tasks	NA	Quick disconnect with automatic latching, may require external torque for hard mate, fine dex- terity (EVA)	NA	Conductor attachment	Electrical continuity (from joint bus thru switch gears to distribu- tion pts)	Possible interference with secondary struc- ture (transport/handl- ing/fastening) unless one end attached prior to transport
table on	105 to 500 m CF to MPTS: 100-1500 m	May require trans- port between attach points and tasks	NA	Same as above. Fastening required at 2000 different locations 10 to 500 m apart	NA	Conductor attachment	Electrical continuity (from joint bus to distri- bution pts) 1 km path	Same as above.
	10 m CF to MPTS: 100-1500 m	Handler may require transport between attach tasks	NA	Attach @ 10 m increments over whole back surface of MPTS (1 km dia)	NA	Conductor attachment	Elec. 785 contin. checks (between sub- array groups)	Possible interference with secondary struc- ture (transport/handl- ing)
	150 m between attach points	Handler requires mobility to build structure	Align beams of struc- ture as each section is assembled (20-50 align- ments) requires angle measurement	Centroidal joint with probe and drogue; requires external torque for hard mate (120 beams)	NA	Beam handling attachment and alignment	NA	Interference with structure as it is built; multiple hand- lers may be required
rted in	~100 m	Assembled at site	NA	Weld counterweight piece; CMG assembly latched to counterweight	NA	Counterweight assembly/ installation	NA	
	70 m, trans- porter to attach point		NA	Latched to MPTS substruc- ture or secondary struc- ture	NA	Installation (if done at MPTS site)	NA	Interference with sec- ondary structure, counterweight support structure, joint (un- less attached to sec. structure prior to support)
rttable on	Between attach pts, 75 to 625 m between subar- rays, up to 500 m	Handler may require transport between attach points, and between subarrays	NA	Quick disconnect concept with automatic latching; may require external tor- que for hard mate; may re- quire attachment period- ically along structure for support	NA	Conductor attachment	Electrical continuity (between drive system & ref- erence sub- arrays) 8 checks	16 connections required over distance of up to 1 km; if accomplished separately
	Between azimuth and ele- vation joints ~100 m	Handler attached to extension structure, joint or MPTS	NA	Mechanically fasten pieces to joint structure (~10 steps)	NA	Installation	NA	
rttable on	Between attach pts, 25 to 100 m	Handler attached to extension structure, joint or MPTS	NA	Quick disconnect concept with automatic latching, may require external tor- que for hard mate, may re- quire fine dexterity (EVA)	NA	Installation/ connection	Electrical continuity (joint to dis- tribution pts)	
	Between attach pts, 20 m	Handler attached to MPTS, or FF	NA	Multiple centroidal joint with probe & drogue, re- quires external torque for hard mate	NA	Installation	NA	
	Within exten- sion structure from trans- porter ~25 m	Handler attached to MPTS, or FF	NA	Latched to extension struc- ture, multiple points (<10)	NA	Installation/ attachment	Electrical continuity (joint to dis- tribution pts)	Interference of handler with extension struc- ture
	CF beam fabrica- tor to structure assy pt: C/C: 35 to 750 m T/T: 40 to 1000m B/T: 30m	Handler may require transport as struc- ture is built, or use several handlers	Align beams of struc- ture as each section is assembled - 20 times C/C or T/T; 3 times B/T- measurement technique required; align each section against exist- ing sections ± 2 cm	Centroidal joint with probe & drogue, requires external torque for hard mate	NA	Alignment, fastening (beams parall- el or @ right angles)	NA	Longer beams may re- quire 2-pt handling

Table 3.4.2-1 (Continued)

SPS ELEMENT	MASS (UNIT/TOTAL)	ELEMENT CHARACTERISTICS			TRANSPORT		HANDLING CONSIDERATIONS
		CONFIGURATION	PROCESS CYCLES	DISTANCE	ATTACHMENT CONSIDERATIONS	DISTANCE	
Electrical Conductors (between Joint and SECS)	63 kg/m, CC: 47,250 kg/conductor TT: 31,500 kg/conductor BT: TBD, small dia	C/C: 17 cm dia 750 m long each TT: 12 cm dia 1 km long each BT: 3 lines, 5 m long each (AC - small dia)	C/C: 4 lines per MPTS TT: 8 lines per MPTS BT: 3 lines	C/C: LF to MPTS - 13 mi FF 18 mi attached TT: CF to Joint - 1 km BT: CF to Joint - 50 m	Transportable on reels; cable avoidance (C/C)	Joint to SECS - C/C-750m TT-1 km	Transporter attach not Accurate
Ball Joint	TBD	Cylinder, 11 m diameter	1	LF to MPTS - 13 mi FF 18 mi attached or to CF	Cable avoidance	Transporter to end of extension structure: 20m to 750m	Handled by transporter or structure Accurate
Frames	140/9240 kg (308/20,328 lb)	4.3 m triangular 65 m x 130 m with diagonal cables	66 per MPTS	CF to MPTS - C/C: 750m TT: 1000m BT: 400m		Transporter to MPTS-130-500m CF to MPTS - 100-1000 m	Frames may be ported to points
Radial Cables	Small	36 @ 150 m long; 144 @ 175 m long	180 per MPTS	C/C: LF to MPTS - 13 mi FF 18 mi attached TT: CF to MPTS - 1 km BT: 100m	Transportable on reels; structure avoidance	130m CF to MPTS 100 to 1000 m	Cables may be ported to points
Secondary Structures	1200/115200 kg (2640/ 253440 lb)	Triangular - 130 m on each side; 7 m high (deployed)	96 per MPTS	C/C: LF to MPTS - 13 mi FF 18 mi attached TT: CF to MPTS - 1 km BT: 400m	Transported folded - TBD; cable avoidance (C/C)	Transporter to top of frames - 500 m max CF to MPTS 100 to 1000m	May be ported to points
Subarrays	200/1570800 kg (440/ 3455760 lb)	10 m x 10 m x 0.25 m each	7854 per MPTS	Same as above	Transportable in packages - TBD	Transporter to secondary structures 500 m max	May be ported to points
Electronics Packages Interconnects (Conductors)	Small	Small diameter 10 m long each	~7000 per MPTS	Same as above		To bottom of subarrays 10-500 m CF to MPTS 100-1000 m	May be ported to points
RF Lines	TBD	Small diameter, lengths 10 m to 500 m	~700 per MPTS	Same as above	Transportable on reels; cable avoidance (C/C)	To bottom of subarrays 10-500 m, CF to MPTS 100-1000 m	May be ported to points
Switch Gears	2000/32000 kg (4400/ 70400 lb)	Rectilinear	16 per MPTS	C/C: LF to MPTS, 13 mi FF 18 mi attached TT: CF to MPTS, 1 km BT: 100m		Transporter to attach points 70 to 500 m	May be ported to points

GENERIC PROCESSES								
TRANSPORT ATTACHMENT CONSIDERATIONS	DISTANCE	HANDLE CONSTRAINTS/SUPPORT RLQMTS.	ALIGN TASK DESCRIPTION	FASTEN TASK DESCRIPTION	ADJUST TASK DESCRIPTION	MONITOR PARAMETER	CHECKOUT PARAMETER	REMARKS
Transportable on reels; cable avoidance (C/C)	Joint to SECS - C/C-750m TT-1 km	Transported between attach points, if not handled Accuracy: < 2 cm	NA	Quick disconnect concept; may require external force torque mechanism and fine dexterity (EVA)	NA	Conductor cable attachment direct or remote visual contact	Electrical continuity (between joint & distribution points) - up to 1 km long	
Cable avoidance	Transporter to end of extension structures 20m to 750m	Handler can be attached to transporter or extension structure Accuracy: < 2 cm	NA	Weld; may require jig	NA	Attachment to structure-once direct or remote visual contact	NA	
	Transporter to MPTS 130-500m CF to MPTS - 100-1000 m	Frames or handler may require transport to attach points	NA	Canted centroidal joint with probe & drogue; requires external torque for hard mate	Top of frame must be in same plane-adjust via radial cables; 54 outer frames adjusted to 12 frames of 1st ring	Frame attachment; frame adjustment; iterative process; top beam of frames must be parallel & in same plane	NA	Frame-to-frame attach angle is different in each succeeding MPTS rings; alignment aids required
Transportable on reels; structure avoidance	130m CF to MPTS 100 to 1000 m	Cables or handler may require transport to attach points	NA	Mechanically attached to frame at one end, adjustable reel at other end	Used to adjust frame positions	Installation and adjustment 180 cables	NA	
Transported folded - TBD; cable avoidance (C/C)	Transporter to top of frames - 500 m max CF to MPTS 100 to 1000m	May require transport to attach points	NA	3-point attachment of base to top of frame structure; 96 times	NA	Attachment of secondary structure to MPTS frame rings	NA	
Transportable in packages - TBD	Transporter to secondary structures 500 m max	May require transport to attach points	NA	3-point attachment to top of secondary structure; 7854 times	NA	Attachment of subarrays - continuous	NA	
	To bottom of subarrays 10-500 m; CF to MPTS 100-1000 m	May require transport to attach points	NA	Mechanically fasten between subarrays, automatic latching	NA	Automatic or manual attachment	Electric continuity	
Transportable on reels; cable avoidance (C/C)	To bottom of subarrays 10-500 m; CF to MPTS 100-1000 m	May require transport to attach points	NA	Lines attached at center of antenna - other ends go to 700 separate points; attach along structure for support	NA	Attachment of RF lines (700)	NA	
	Transporter to attach pts 70 to 500 m	May require transport to attach points	NA	Contact latches to bottom of secondary structure	NA	Switch gear placement	NA	Could be attached to secondary structure prior to transport

FOLDOUT FRAME

Table 3.4.2-1 (Continued)

SPS ELEMENT	MASS (UNIT/TOTAL)	ELEMENT CHARACTERISTICS		TRANSPORT			HANDLE CONSTRAINTS
		CONFIGURATION	PROCESS CYCLES	DISTANCE	ATTACHMENT CONSIDERATIONS	DISTANCE	
Support Arm Beams	C/C: 1500 kg TT: 940 kg BT: 240 kg	5.5 m triangular, Lengths: C/C: 2 @ 165 m, 50 @ 65 m, 4 @ 150 m TT: Same as C/C. BT: 4 @ 65 m, 4 @ 25 m, 10 @ 30 m, 4.3 m triangular	60 per HPTS (C/C and TT) 20 for BT HPTS	NA (see Handle)	NA	Transporter to assembly - 25 to 200 m	Handler attached transporter, or extension ture; beams for may require transport
Structure Beams - Rotary Joint	23 kg each 2300 kg total	4.3 m triangular, 50 to 130 m long	~100	NA (see Handle)		~100 m	Beams or handle may require port to site
Vernier Latitude Actuators (RTA)	NA (see Remarks)	Part of RTA/power conversion equipment	3	NA	See Remarks	NA	See Remarks
Facility Beams (for HPTS CFs)	54 kg/ea	4.3 m triangular x 150 m long	15 per HPTS CF	SECS CF to HPTS CF site 150 m	Access thru facility framework	~150 m	Nodal dropping; accuracy on lateral, 1 m
Beam Builders (in HPTS CFs)	30,000 kg each	7 m dia, cyl. - 21 m long 9 m dia, cyl. - 27 m long	3 per HPTS 1 per HPTS (TT) 3 per HPTS (C/C)	LF to CF (C/C): 13 m FF, 18 m attached CF to CF (TT) 300 m LF to CF (BT): TBD		~150 m	Place beam in proper location in CF; handle attached to CF ture

GENERIC PROCESSES							REMARKS
TRANSPORT ATTACHMENT CONSIDERATIONS	HANDLE		ALIGN		FASTEN	ADJUST	
	DISTANCE	CONSTRAINTS/ SUPPORT REQMS.	TASK DESCRIPTION	TASK DESCRIPTION	PARAMETER	CHECKOUT PARAMETER	
Remarks	Transporter to assembly point - 25 to 200 m	Handler attached to transporter, joint or extension structure; beams or handler may require transport	±2-cm; align beams of structure as each section is assembled ~20 times (C/C & TT) ~5 times (BT); alignment measurement technique required; align each section against existing sections.	Centroidal joint with probe and drogue, requires external torque for hard mate	NA	Handling, attachment, alignment of beams	Longer beams may require 2-pt handling
	~100 m	Beams or handler may require transport to site	NA	Centroidal joint w/probe and drogue, requires external torque for hard mate	NA	Handling/Assembly	
	NA	See Remarks	NA	Mechanically mate actuator between extension structure & RTA (might require EVA)	NA	NA	In GEO, after MPTS attachment to SC Modules
	~150 m	Nodal drogue fitting; accuracy: 1 cm lateral, 5 angular	NA	Centroidal joint w/probe and drogue; external torque required for hard mate	Adjust beams to align facility (30 angles)	Alignment-30 angles; jigs or optical device required (EVA installed)	Only work base may be preceeding beam, not structurally stable
ess thru facility framework	~150 m	Place beam builders @ proper location in CF; handler attached to CF structure	NA	Mechanically fasten to CF structure - 3 to 6 beam builders to be attached	NA	NA	Stockpiling of beams may be necessary

FOIA(b)(7) DECLASS

Table 3.4.2-1 (Continued)

SPS ELEMENT	ELEMENT CHARACTERISTICS			TRANSPORT		HANDLE	
	MASS (UNIT/TOTAL)	CONFIGURATION	PROCESS CYCLES	DISTANCE	ATTACHMENT CONSIDERATIONS	DISTANCE	CONSTRAINTS/ SUPPORT REQUIREMENTS
Construction Equip- ment (C/C Option A)	TBD	Handling for installing SECS equipment	As required	600 m from CF to center of SECS supports	Transport inside 100 m column desir- able because of cables outside truss	Up to 600 m	Assume transport system; installed columns are built
Solar Cell Packages (C/C Option A)	4000 to 50,000 kg per package 28.7 x 106 kg per SECS side	10 x 10 m x thickness of 0.1 to 8 meters	As required	Up to 6000 m		<100 m	10 packages per trough; 300 pac- ages/quadrant
Concentrator Rolls (C/C Option A)	4000 to 50,000 kg per roll	100 meters long x up to 1.0 m diameter	120 rolls per SECS side	Up to 6000 m		<100 m	
Secondary Tape Reels (C/C Option A)	10 kg each	Small reels	844 reels total	Up to 12,000 m	Could be packaged with several reels	<100 m	Installed along sides of column; hold for spot a
Automated Construc- tion Equipment (TT Option A)	TBD	TBD	~36 places	Up to 2600 m from LF		<100 m	TBD
Long-boom SC Con- struction Equipment (BT Option A)	8000 kg	Long truss structure with attached mobile manipulators	Installed once	TBD		TBD	
Prime Cables (C/C Option A)	Small	Ends of small cables moved in preparation for attachment to solar cells	33 cable ends/quadr- ant			<50 m	Hold for attach- carry coded cabl along as work pr ceeds along col
Secondary Tape At- tachments to Periph- eral Cables (C/C Option A)	22 Newton pull force at each tape	Pull on tapes deploy solar cell and concen- trator packages				Up to 14,000 m	Deployment depen- items premarked located
Power Distribution Connectors to Periph- eral Cables (C/C Option A)		Concentrator conduc- tive material joined in connector for joining w/peripheral cable	60 connect- ors each quadrant				
Solar Cell Roll Mounts (C/C Option B)	200 kg ea 24,000 kg total	Mounts to hold SC roll	30 pairs per quad- rant	LF to CF 21 km TF 30 km attached CF to site 6 km		~25 m	
Solar Cell Rolls (C/C Option B)	48,000 kg max	Cylindrical rolls	~180 per quadrant	Same as above		~25 m	
Secondary Structures (MPTS Option A)	1200 kg each	Triangular 130 m on each side x 7 m high (deployed)	96 per MPTS	C/C: LF to MPTS- 21 km FF, 30 km at- tached; TT: CF to MPTS, 1 km BT: ~100 m	Transported folded - TBD	Trans- porter to site ~500 m	Handling task over 1 km dia na

GENERIC PROCESSES								
PORT ATTACHMENT CONSIDERATIONS	DISTANCE	HANDLE CONSTRAINTS/SUPPORT REQTS.	ALIGN TASK DESCRIPTION	FASTEN TASK DESCRIPTION	ADJUST TASK DESCRIPTION	MONITOR PARAMETER	CHECKOUT PARAMETER	REMARKS
port inside column desired because of outside truss	Up to 600 m	Assume transport system installed as columns are built						
	<100 m	10 packages per SECS trough; 300 packages/quadrant		Solar cells on flexible substrate, in panel form; attached to column adapter frame at trough bottom. Rings at each panel are hooked on secondary tapes (1800 rings/quadrant)				Difficult to automate fastening; GEO environment constraints on EVA crewman
	<100 m			Flexible AL material; roll attached to column fittings; automatically attached to solar cell material; periodic edge rings attached to secondary tapes (900 ring/quadrant)				Difficult to automate fastening; GEO environment constraints on EVA crewman
d be packaged several reels	<100 m	Installed along both sides of columns, hold for spot attach		Reel base plate mechanically joined to column structure				
	<100 m	TBD						
	TBD							
	<50 m	Hold for attachment, carry coded cables along as work proceeds along columns		Cable ends attached to SECS rings, 264 total connections; max of 10 connections @ one operation.				
	Up to 14,000 m	Deployment dependent items premarked and located		Join secondary tapes to peripheral cables to maintain SECS tension (211 each-quadrant) SECS connector joined to peripheral cable pig-tail connector				Difficult to automate fastening; GEO environment; no support structure, FF applicable.
	<25 m			Fasten mounts to column structure				
	<25 m			Insert in mounts; splice in to zippered connection				
transported folded	Transporter to site <500 m	Handling task occurs over 1 km dia antenna	NA	Temporarily fasten secondary structures to each other (3 attach points per side, 432 total attachments)	Remove temporary attachments after radial cables are installed			

FOLDOUT FRAME

Table 3.4.2-1 (Continued)

SPS ELEMENT	ELEMENT CHARACTERISTICS			TRANSPORT		GENERAL	
	MASS (UNIT/TOTAL)	CONFIGURATION	PROCESS CYCLES	DISTANCE	ATTACHMENT CONSIDERATIONS	DISTANCE	HANDLE CONSTRUCTION SUPPORT
PLANNED UNSCHEDULED SERVICE							
Resupply Beam Builders	TBD	Stock material on rolls	As required	C/C: LF to CF 13 m FF 18 m attached TT: LF to site 2600 m BT: LF to site 2700 m FF, 5600 m attached		<2 m	Rolls (mat material) aids in acceptance, man required
SPS Commodity Modules (e.g., ACS tanks)	TBD	Compact package ~1 m ³ in volume	As required	C/C: 13 m FF 18 m attached TT: up to 17 km BT: 2700 m FF, 5600 m attached	Need to be hard attached to structure to make module exchange	TBD	Insert in module
Fastening Device Resupply	TBD	Material used in fastening device (e.g., weld material, glue)	As required	C/C: LF to CF 13 m FF 18 m attached CF to site 4200 m TT: <4 km BT: 2.7 km FF, 5.6 km attached		<2 m	Operation remotely by crewman
Replace/Recharge Battery Systems	TBD	TBD	As required			<2 m	Dock equipment facility area
Service Equipment Propulsion Tanks	TBD	TBD	As required			<2 m	Hold for controlled or by IVA
PLANNED SCHEDULED MAINTENANCE							
Lubrication	Small	Lubricate construction equipment	As scheduled	C/C: 200 m TT: 4 km BT: 5.6 km	Environmental impacts/induced effects	At point of application	Spot position or automation
Remove Reflector Facet Layer	~30 kg	EVA crewman or remote controlled EOTS	67000 facets for 30 year life	BT only 2.7 km	100 per day if all replaced in 2-year period	TBD	Remove top facet material (grab small tab)
He/NaK System Recharge	Service cart - TBD	Cart with large supply tank	As scheduled	BT only, up to 9 km FF		<25 m hookup dist. <300 m from LF to CF frame	Environmental
CONTINGENCIES							
Troubleshooting	135-225 kg (EVA); other TBD	EVA crewman with instruments; remote controlled viewing device	As required	C/C: up to 16 km TT: up to 28 km BT: up to 10 km		<5 m	Instrument requires viewing device or remote
Personnel Rescue	~200 kg - single person	Single or multiperson vehicle	As required	In vicinity of facility		Near or within facility	

GENERIC PROCESSES								
TRANSPORT ATTACHMENT CONSIDERATIONS	DISTANCE	HANDLE CONSTRAINTS/ SUPPORT REQTS.	ALIGN TASK DESCRIPTION	FASTEN TASK DESCRIPTION	ADJUST TASK DESCRIPTION	MONITOR PARAMETER	CHECKOUT PARAMETER	REMARKS
Need to be hard attached to structure to make module exchange	<2 m	Rolls installed and material fed out; aids in bulker receptacle; IVA crewman required	NA	Latch roll in receptacle and feed material strip in machine slot	NA	NA	NA	
	TBD	Insert in guides for module insertion	NA	Standard attachment mechanism designed for use with remote controlled equipment-module attach fittings	NA	NA	NA	
	<2 m	Operation controlled remotely or by IVA crewman	NA	Insert canister into device and cycle operation	NA	NA	NA	Small devices reloaded IVA; EVA required to service large equipment
	<2 m	Dock equipment to facility maintenance area	NA	Battery lead-connection open/close	NA	Automatic shutdown capability; CSM-crewman in vicinity	Verify service ability & charge (crewman or computer)	Operation controlled remotely or by IVA crewman
	<2 m	Hold for docking; controlled remotely or by IVA crewman	NA	Connect propellant fill and drain lines	NA	Mechanical and/or electrical; redundancy required leak surveillance		Remote control of flow (start/stop); in explosion-safe area
Environmental impacts/induced effects	At point of application	Spot position - EVA or automated	NA	Attach dispenser to fitting	NA	NA	NA	Assume EVA operation or eliminate by automatic lubrication
100 per day if all replaced in 2-year period	TBD	Remove top layer of facet material (grab small rip tab)	NA	NA	NA	NA	NA	Disposal stowage, potentially hot environment, EDTS must stand off
	<25 m hookup dist. <300 m from LF to CF frame	Environment	NA	Connectors TBD, service lines to SPS system	NA	Mechanical or electrical - leak surveillance		Assume requires EVA crewman to operate equipment - few occurrences
	<5 m	Instrumentation - requires dexterity; viewing device - EVA or remote	NA	Connect instrumentation to SPS test points	NA	Physical observation	Automated c/o to minimize manned involvement	Requires caution and dexterity - potential hazards in power circuits
	Near or within facility		NA	NA	NA	NA	NA	

FOLDOUT FRAME

Table 3.4.2-1 (Concluded)

SPS ELEMENT	MASS UNIT/TOTAL	ELEMENT CHARACTERISTICS		GENERIC PROCESSES				
		CONFIGURATION	PROCESS CYCLES	TRANSPORT	ATTACHMENT CONSIDERATIONS	HANDLE	ALIGN	
				DISTANCE		DISTANCE	CONSTRAINTS/SUPPORT REQTS.	TASK DESCRIPTION
Return Failed Parts to Shop	20-500 kg 100-2000 kg	Mobile/portable construction equipment SPS operational modules (e.g., subarrays)	As required	Up to 6 km MPTS: 1 km C/C: 16 km FF: 22 km attached TT: 14 km max BT: 10 km max FF	Provisions for docking while removing module; interference in dense structure areas	Near TBD	Hard docking	NA
Repair Failed Parts on Site								
- Material Separation	<100 kg plus CM	Material separation - C/C & TT concentrator	As required	Up to 16 km	EVA crewman with repair kit	Hands on	Environment	
- System leak on BT PCS	TBD	- BT reflector Service cart	As required	Up to 10 km				
- Cable break (C/C SEES support, TT tension rods, MPTS radial cables)	TBD (<100 kg + CM)	Within primary structure	As required	Up to 9 km C/C: 14 km TT: 5 km MPTS: 5 km	Crewman operated detector EVA with repair kit and free-flyer (structure/cable interference)	~25 m Hands on	Environment	
- Electrical conductor break (C/C peripheral cable, TT power cable, MPTS power cable)	TBD (<100 kg plus CM)	Free-flyer (C/C and MPTS), rail transporter (TT)	As required	C/C: 10 km TT: 3 km MPTS: 1 km	EVA with repair kit and FF or rail transporter	Hands on	Environment	
- Component replacement (C/C tape reel, TT ACS sensor, BT transformer)	TBD (<100 kg plus CM)	EVA with support equipment	As required	C/C: 14 km TT: 15 km BT: 5 km		Hands on	Environment	
- Construction equipment repair	TBD (<200 kg plus CM)	EVA with repair tool kit	As required	Up to 4 km		Hands on	Environment	Align construction equipment when applicable after repair

OLDOUT FRAME

GENERIC PROCESSES								REMARKS
TRANSPORT	HANDLE	ALIGN	FASSEN	ADJUST	MONITOR	CHECKOUT		
ATTACHMENT CONSIDERATIONS	DISTANCE	CONSTRAINTS/ SUPPORT REQTS.	TASK DESCRIPTION	TASK DESCRIPTION	TASK DESCRIPTION	PARAMETER	PARAMETER	
5	Near	NA						
Provisions for docking while removing module; interference in dense structure areas	TBD	Hard docking						
16	Hands on	Environment		Parts/repair kit, remove replace flexible material		Physical observation, damage assessment		
10								
9	~25 m	Environment		Leak repair kit		Requires damage assessment, fix requirements evaluation, repair verification	Repair verification	Requires stable base, requires on-site judgment and dexterous activities
4	Hands on	Environment		Cable splice kit				
5								
0	Hands on	Environment		Conductor repair kit				
1								
4	Hands on	Environment		Replace SPS LRU				LRU replacement could be automated
4	Hands on	Environment	Align construction equipment when applicable after repair	Replace SPS LRU				

3.5 SPS Construction Equipment Support Requirements

3.5.1 Categories of SPS Elements

The analyses of SPS elements by generic process showed that the majority of elements could be categorized into one of six major groups (I-VI) due to commonality in the tasks required by the particular elements. The remainder of the elements were classified separately (VA, VIA, VIB and VII), because they are highly concept dependent, or require distinct or unique assembly/construction tasks. Table 3.5.1-1 gives the definitions of the categories and Table 3.5.1-2 lists the major categories of elements for each of the SPS concepts. As Table 3.5.1-2 shows, each of the SPS concepts include elements in the six major categories. Although the specific elements in each category differ based upon the SPS concept, the general characteristics of the elements in each category are similar across the concepts.

Table 3.5.1-1 SPS Element Category Definitions

MAJOR GROUPS

- I. Triangular Beams - 2.45 to 20 meters on a side, lengths 50 meters to 4km, from 10 to 100 beams per element.
- II. Facilities/Large Modules - large, self-contained units, infrequent operations, not part of SPS itself.
- III. Cables - structural only, long spans, small diameter, 10 to 200 cables per element.
- IV. Electrical Conductors - diameters 1 to 20 centimeters, lengths 10 meters to 16 km, 6 to 1000 per element.
- V. Preassembled Structures - large, varying shapes, 5 to 5000 per element, mechanical interface only.
- VI. Preassembled Packages - varying shapes/masses, 1 to 8000 per element, multiple interfaces.

CONFIGURATION/CONSTRUCTION UNIQUE ITEMS

- VA. Cavity Absorber Shell - ref Boeing Thermal SPS scenario, paragraph 2.1.1.1.
- VIA. Joint/Power Transfer Mechanism - ref Column/Cable SPS scenario, paragraph 4.2.2 and Truss Type SPS scenario, paragraph 2.2; Turbogenerator Sets - ref Boeing Thermal SPS scenario, paragraph 2.1.1.3.
- VIB. Reflector Facets - ref Boeing Thermal SPS scenario, paragraph 2.1.2.6.
- VII. MPTS Subarrays - ref Column/Cable SPS scenario, paragraph 4.2.4 (or applicable paragraph in other scenarios).

Table 3.5.1-2 Categories of SPS Elements by Concept

COLUMN/CABLE		TRUSS TYPE		BOEING THERMAL	
I.	Triangular Beams	I.	Triangular Beams	I.	Triangular Beams
II.	Facilities/Large Modules	II.	Facilities/Large Modules	II.	Facilities/Large Modules
III.	Cables	III.	Cables	III.	Cables
IV.	Electrical Conductors	IV.	Electrical Conductors	IV.	Electrical Conductors
V.	Preassembled Structures	V.	Preassembled Structures	V.	Preassembled Structures
VI.	Preassembled Packages	VI.	Preassembled Packages	VA.	Cavity Absorber Shell
VIA.	Ball Joint/Power Transfer Mechanism	VIA.	Rotary Joint Drive System/Power Transfer Mechanism	VI.	Preassembled Packages
VII.	MPTS Subarrays	VII.	MPTS Subarrays	VIA.	Turbogenerator Sets
				VIB.	Reflector Facets
				VII.	MPTS Subarrays

The commonality considerations made evident by such categorization are both quantitative (based on element size, mass, frequency of occurrence, etc) and functional (involve the same generic processes).

3.5.2 Identification of Construction Equipment and Support Requirements

The generic processes matrix (see Table 3.4.2-1) and the SPS element groups were utilized to identify the construction functions to be performed upon each group for each SPS concept. From these generic functions potential construction equipment was defined, and the anticipated performance capabilities (where available) of that equipment were established. It should be noted that although over a dozen major pieces of construction equipment have been identified, performance characteristics or detailed concepts exist only for a few of those items. Table 3.5.2-1 lists the construction equipment required, and Figures 3.5.2-1, 3.5.2-2 and 3.5.2-3 show three items for which some detail does exist.

Support requirements were developed for each type of construction equipment identified. Tables 3.5.2-2, 3.5.2-3 and 3.5.2-4 present for each SPS a list of the element groups, their corresponding construction function, the potential equipment which would accomplish the functions, and the support requirements of that construction equipment. Although many of the 250 line items generated were common to all three SPS concepts, separate lists were maintained as inputs to Part II of the study.

Table 3.5.2-1 Construction Equipment List

MAJOR SYSTEM EQUIPMENT

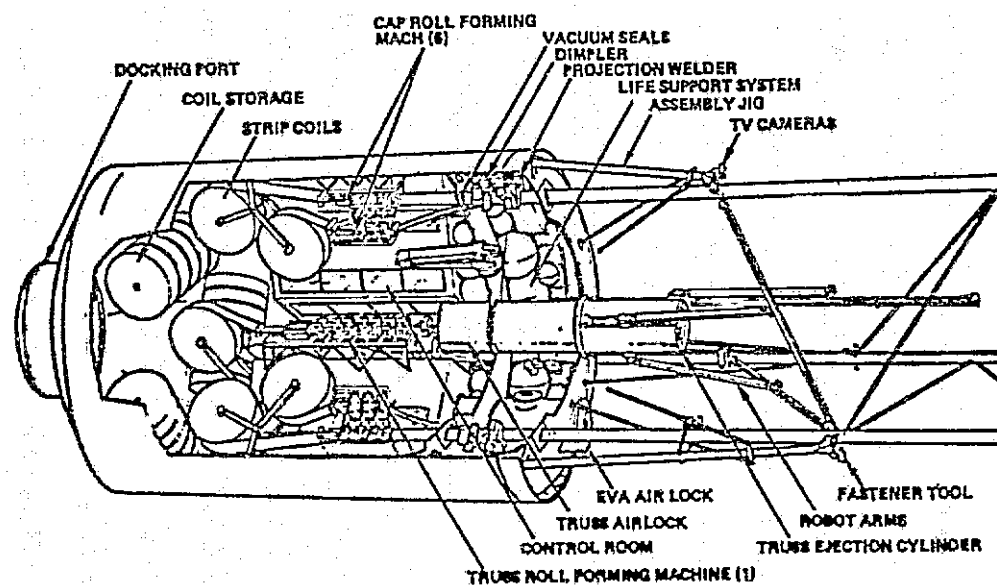
- Construction Facilities
- Beam Fabricator
- Beam Handler
- Beam Fastener
- Cable Reel Dispenser
- Cable Routing Mechanism
- Electrical Conductor Installer

LOGISTICS

- Specialized Transporters (free-flying and structure attached)
- Orbital Transfer Vehicles

SPECIALIZED INSTALLERS

- SPS Package Installer (solar cell material, reflector material)
 - Subarray Installer
 - Generator Set Installer
 - Thermal Collector Installer
 - Facet Installer
 - Switch Gear/Pointing Computer Installer
 - Power Bus Installer
 - Ball Joint Installer
- Boeing Thermal SPS only



Rockwell Concept

Figure 3.5.2-1 Typical Construction Equipment - Beam Fabricator

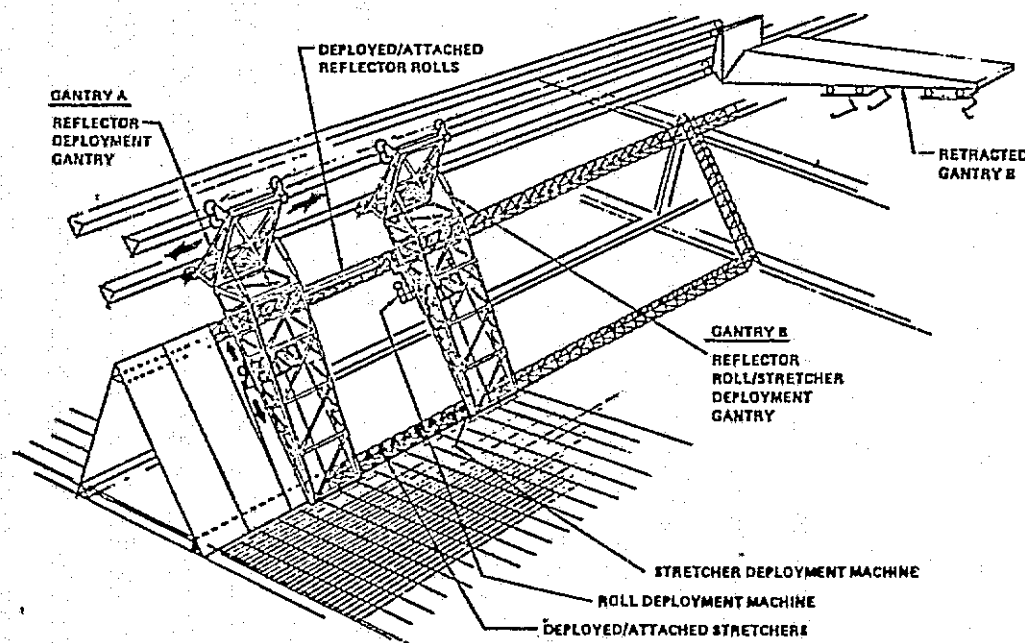
CHARACTERISTICS:

(For 20-meter beams)

- 25-meter diameter x 40-meters long
- Fabricates triangular beams @ 15 meters/hour
- Typical number required -
57 for truss type SPS construction facility
- Beam material -
metal or composite

SUPPORT REQUIREMENTS:

- Initial placement/attachment/alignment
- Material resupply via docking port
- Checkout/monitoring
- Operational maintenance



Boeing Concept

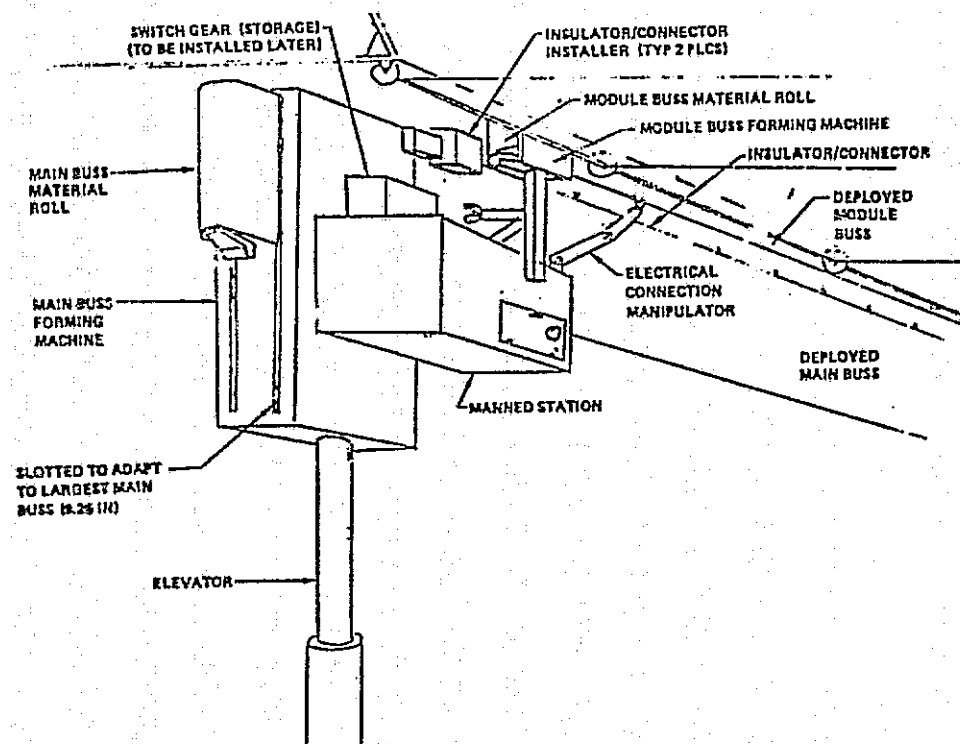
CHARACTERISTICS:

- Gantry B places reflector packages (20-meters wide x 650-meters of material) on structure.
- Gantry A stretches material and seals edges.
- 90 minutes allowed to deploy each 20-meter x 650-meter strip (33 strips per side).
- 2 hours allowed to seal edges.
- 16 gantries required (4 troughs, 2 gantries each on both sides of trough).
- Gantry structure - 20-meters wide x 650-meters long.

SUPPORT REQUIREMENTS:

- Initial gantry placement.
- Reflector package resupply.
- Checkout/monitoring.
- Operational maintenance.

Figure 3.5.2-2 Typical Construction Equipment - Reflector Installer - Truss Type SPS



Boeing Concept

CHARACTERISTICS:

- Fabricates module bus and main bus on both sides of troughs (6.2 meters/hour allowed).
- Installs switch gear at end of each bay.
- Makes electrical connections.
- Manned operation, manipulator control.
- 8 installers required.

SUPPORT REQUIREMENTS:

- Initial placement
- Material resupply
- Checkout/monitoring
- Operational maintenance

Figure 3.5.2-3 Typical Construction Equipment - Bus/Switch Gear Installer

Table 3.5.2-2 Column/Cable SPS Elements and Support Requirements

SPS ELEMENTS	CONSTRUCTION FUNCTION	POTENTIAL CONSTRUCTION EQUIPMENT	SUPPORT REQUIREMENTS
I. TRIANGULAR BEAMS - Facility Beams - Column Hub Beams - Column Beams - MPTS Extension Structure and Counterweight Cone	- TRANSPORT beams to construction facilities and sites - HANDLE beams to assemble columns build structure - ALIGN beams as sections are assembled - FASTEN beams together - probe and drogue fitting requiring external torque - ADJUST beam lengths (only when building CFs) - MONITOR adjustment or alignment of beams	Beam and Beam Assembly Transporter - Receive beams - Beam holddowns - Beam release Beam Handler - Beam translation - Position for alignment - Adjust after fastened Beam Fastener - Fasten beams - Adjust beams	Mobile Beam Transporter (on Structure) - Assemble on orbit or launch from ground - Transport to structure - Placement on rails or cables - Communications link - Electrical power recharge - Operational checkout - Maintenance and repair Fixed Base Manipulators - Assemble on orbit or launch from ground - Transport to construction site - Alignment for mounting - Fasten to construction facility - Service and repair Small Highly Dexterous Manipulator - Launched from ground - Transport to construction site - Interface with fixed base manipulator - Storage port on CF - Maintenance and repair
II. FACILITIES/LARGE MODULES - Preassembled CFs - Beam Builders	- TRANSPORT modules to facilities (if not transported with facilities) - HANDLE facilities for docking, modules for positioning - ALIGN as required - FASTEN equipment to existing structure - ADJUST beam end fittings (facilities only) - MONITOR docking	Beam Builders - Fabricate (10 meter) triangular beams - Material forming - Material curing - Fastening cross-members - Beam alignment - Manned or unmanned Preassembled CF Sections - Section joining interfaces - Self-aligning aids - Erectable structure	Mount Beam Builders onto Construction Jig - Transport to construction site - Docking or EE grip interface - Position alignment for mounting - Fasten to construction facility - Checkout operations - Raw material handling - Resupply consumables - Maintenance Connect Sections Together - Transfer section to connection point - End effector interface - Connection alignment
III. CABLES - Peripheral (8) - Main (32) - Prime (144) - MPTS Radial (180)	- TRANSPORT cable reels to construction facility/site - HANDLE cables - deploy from facility or string between structure - FASTEN reels and cable ends to existing structure - ADJUST cables - release/retension	Cable Reel Transporters - Dock to reel stowage facility - Receive reels from stowage - Reel holddowns - Transport between stowage and use points - Dock to SPS work site - Release reels Cable Reel Dispenser Mechanism - Receive full reels/remove spent reels - Cable feed - Cable connect to other cable - Provide cable tension requirements - Cable cutter - Cable fasten to structure Cable Routing Mechanism - Grip and hold cable end - Cable translate capability - Cable alignment - Cable fasten to structure	Compatible Docking Parts - Pick up point - Disposition point Load Transporter - Transfer reels from Transporter to Cable Dispenser Installation of Cable Dispenser at Use Point - Release holddown fastener - Transfer to new use location - Position for fastening - Check alignment - Fasten to structure - System checkout - Maintenance - failure isolation contingency mode failure repair Same as above, plus - Collision avoidance with existing cables - Viewing and lighting to find and grip cable end - Transfer along cable routing - Coordinate tension requirements at fasten points

Table 3.5.2-2 (Continued)

SPS ELEMENTS	CONSTRUCTION FUNCTION	POTENTIAL CONSTRUCTION EQUIPMENT	SUPPORT REQUIREMENTS
IV. ELECTRICAL CONDUCTORS - Between SECS and MPTS Joint (4) - From MPTS Joint to Switch Gears (16) - Over Joint Buses - From Switch Gears to Distribution Points on MPTS (~1000) - Between Subarrays (~7000) - Peripheral Cables (~240)	• TRANSPORT conductors (possibly on reels) to attach locations • HANDLE conductors between and @ attach locations (over, on or thru structure) • FASTEN conductors @ ends (connector requiring external torque) and along structure • CHECKOUT electrical continuity	Electrical Conductor Reel Transporter • Dock to reel stowage facility • Receive reels from stowage • Reel holdowns • Transport between stowage and use points • Dock to SPS work site • Release reels Electrical Conductor Installer • Receive full reels/remove spent reels • Conductor feed control • Conductor routing • Fasten conductor to structure • Conductor cutter • Conductor connector	Transport Conductor Reels to Point of Use • Compatible docking ports • Load reels onto transporter • Transfer reels to conductor installer • Collision avoidance capability Routing Conductors on Structure • Reel handling mechanism • Mobility capability on structure surface (or internal) • Electrical recharge • Stowage port for non-use times • Consumable parts resupply • Maintenance and repair • Connector torques
V. PREASSEMBLED STRUCTURES - MPTS Secondary Structure - MPTS Frames	• TRANSPORT to MPTS assembly site (over existing substructure) • HANDLE structure for assembly • FASTEN to substructure (3 point attach) or to each other (centroidal joint with probe and drogue requiring external torque) • ADJUST (frames only) using cable tension and frame positioning	Assembled Structures Transporter (FT) • Grip structure (on CG) • Maneuver structure • Transport structure to SPS assembly site • Release structure to handling equipment Structure Attached Transporter • Move on rails or cables • Handling structures • Aligning structures (gross)	Transport MPTS Structure to Assembly Site • Compatible handling interface • Docking port • Services, power, propellants, etc • Collision avoidance SPS structure • Maintenance and repair Transport SPS Elements on SPS Structure • Transport platform • Existing structure with rails or cables • Communications link • Power source (outlets) • Fabricate unit • Transport unit to SPS site • Position on rails or other • Operational checkout • SPS elements resupply • Maintenance and repair • Relocate on structure
VI. PREASSEMBLED PACKAGES - Solar Concentrators - Solar Cells - Switch Gears - Pointing Computer	• TRANSPORT packages to attach site (over existing structure, or thru structure) • HANDLE packages @ attach locations (discrete positions) • FASTEN packages to existing structure • ALIGN packages to structure	SPS Package Transporter • Dock to package stowage facility • Receive packages from stowage • Secure package holdowns • Transport between stowage or fabrication facility and CC site • Release packages SPS Package Installer (SPI) (1) Solar Cells and Solar Concentrators • Receive packaged elements • Align for layout • Fasten end to peripheral cable • Layout packages • Check alignment • Fasten to structure • Perform subelement performance check (2) Switch Gears and Pointing Computer	Transport packages to work site • Compatible docking port • Package loading device • Transfer packages to railed transporter or installer Assumes packages are deployed from main beam as unit is built • Potential internal location of structure • Mount many SPI units on main beam • Communications link • Align and place on cables • Operational checkout • Resupply packages to SPI • Maintenance and repair • Relocate on new SPS structure

Table 3.5.2-2 (Concluded)

SPS ELEMENTS	CONSTRUCTION FUNCTION	POTENTIAL CONSTRUCTION EQUIPMENT	SUPPORT REQUIREMENTS
VIA. <u>ROTARY JOINT DRIVE SYSTEM & POWER TRANSFER MECHANISM</u>	• TRANSPORT equipment to rotary joint location (over or thru existing extension structure) • HANDLE equipment into position in structure • FASTEN pieces to and within structure	<u>Transport to Assembly Site</u> • Transporter (FF or attached) • Special manipulator for equipment handling/fastening (may require manned assistance)	<u>Transport from Launch Vehicle to Construction Site</u> • Transport vehicle (FF or attached) • Manipulator setup maintenance • Manned vehicle with manipulators (if required)
VII. <u>SUBARRAYS (MPTS)</u>	• TRANSPORT subarrays to MPTS surface (over structure) • HANDLE subarrays at attach locations (7854) • FASTEN subarrays to secondary structures (3 point, mechanical)	<u>MPTS Subarrays Installer</u> • Transporter (FF and attached-to-structure) • Multiple mobile manipulators for handling/fastening (manned assistance may be required)	<u>Transport from Fabrication Facility to MPTS Surface</u> • Transport vehicles - FF and attached • Rail/track system setup, maintenance and repair • Docking facilities • Manned vehicle with manipulators (if required)

Table 3.5.2-3 Truss Type SPS Elements and Support Requirements

SPS ELEMENTS	CONSTRUCTION FUNCTION	POTENTIAL CONSTRUCTION EQUIPMENT	SUPPORT REQUIREMENTS
I. TRIANGULAR BEAMS - SECS Support Trusses (1200) - MPTS Extension Structure	HANDLE beams to assemble structure ALIGN beams as sections are assembled. FASTEN beams together - probe and drogue requiring external torque (multiple joints @ one operation) ADJUST beam end fittings to align diagonal beam plane	Beam and Beam Assembly Transporter - Receive beams - Beam holddowns - Beam release Beam Handler - Beam translation - Position for alignment - Adjust after fastened Beam Fastener - Fasten beams - Adjust beams	Mobile Beam Transporter (on Structure) - Assemble on orbit or launch from ground - Transport to structure - Placement on rails or cables - Communications link - Electrical power recharge - Operational checkout - Maintenance and repair Fixed Base Manipulators - Assemble on-orbit or launch from ground - Transport to construction site - Alignment for mounting - Fasten to construction facility - Service and repair Small Highly Dexterous Manipulator - Launched from ground - Transport to construction site - Interface with fixed base manipulator - Storage port on CF - Maintenance and repair
II. FACILITIES LARGE MODULES - Beam Builders - Preassembled CFs	TRANSPORT to facilities (if not transported with facilities) HANDLE to orient in proper positions ALIGN builders in CFs (if required) FASTEN to structure	Beam Builders - Fabricate (10 meter) triangular beams - Material forming - Material curing - Fastening cross-members - Beam alignment - Manned or unmanned Preassembled CF Sections - Section joining interfaces - Self-aligning aids - Erectable structure	Mount Beam Builders onto Construction Jig - Transport to construction site - Docking or EE grip interface - Position alignment for mounting - Fasten to construction facility - Checkout operations - Raw material handling - Resupply consumables - Maintenance Connect Sections Together - Transfer section to connection point - End effector interface - Connection alignment
III. CABLES - MPTS Radial Cables	TRANSPORT cables (probably on reels) to MPTS substructure construction site (over existing structure) HANDLE cables between and @ attach points FASTEN cables @ ends ADJUST cables to position frames (substructure)	Cable Reel Transporters - Dock to reel stowage facility - Receive reels from stowage - Reel holddowns - Transport between stowage and use points - Dock to SPS work site - Release reels Cable Reel Dispenser Mechanism - Receive full reels/remove spent reels - Cable feed - Cable connection to other cables - Provide cable tension - Cable cutter - Cable fastened to structure	Transport Cable Reels to MPTS Use Points - Compatible docking ports - Load reels onto transporter - Transfer reels to cable dispenser Installation of Cable Dispenser at Use Point - Release holddown fastener - Transfer to new-use location - Position for fastening - Check alignment - Fasten to structure - System checkout - Maintenance Cable Installation - Cable stringer

Table 3.5.2-3 (Concluded)

SPS ELEMENTS	CONSTRUCTION FUNCTION	POTENTIAL CONSTRUCTION EQUIPMENT	SUPPORT REQUIREMENTS
IV. ELECTRICAL CONDUCTORS - Between SECS and MPTS Joint (4) - From MPTS joint to switch gears (16) - Over joint buses - From switch gears to distribution points on MPTS (~1000) - Between sub-arrays (~7000)	• TRANSPORT conductors (possibly on reels) to attach locations • HANDLE conductors between and @ attach locations (over, on or thru structure) • FASTEN conductors @ ends (connector requiring external torque) and along structure • CHECKOUT electrical continuity	Electrical Conductor Reel Transporter • Dock to reel stowage facility • Receive reels from stowage • Reel holdowns • Transport between stowage and use points • Dock to SPS work site • Release reels Electrical Conductor Installer • Receive full reels/remove spent reels • Conductor feed control • Conductor routing • Fasten conductor to structure • Conductor cutter • Conductor connector	Transport Conductor Reels to Point of Use • Compatible docking parts • Load reels onto transporter • Transfer reels to conductor installer Routing Conductors on Structure • Reel handling mechanism • Mobility capability on Structure surface (or internal) • Electrical recharge • Stowage port for non-use times • Consumable parts resupply • Maintenance and repair
V. PREASSEMBLED STRUCTURES - MPTS Secondary Structure - MPTS Frames	• TRANSPORT to MPTS assembly site (over existing substructure) • HANDLE structure for assembly • FASTEN to substructure (3 point attach), or to each other (centroidal joint with probe and drogue requiring external torque)	Assembled Structures Transporter (EF) • Grip structure (on CG) • Maneuver structure • Transport structure to SPS assembly site • Release structure to handling equipment Structure Attached Transporter • Move on rails or cables • Handling structures • Aligning structures (gross)	Transport MPTS Structure to Assembly Site • Compatible handling interface • Docking port • Services, power, propellants, etc • Collision avoidance SPS structure • Maintenance and repair Transport SPS Elements on SPS Structure • Transport platform • Existing structure with rails or cables • Communications link • Power source (outlets) • Fabricate unit • Transport unit to SPS site • Position on rails or other • Operational checkout • SPS elements resupply • Maintenance and repair • Relocate on structure
VI. PREASSEMBLED PACKAGES - Solar Concentrators - Solar Cells - Switch Gears - Pointing Computer	• TRANSPORT packages to attach site (over existing structure, or thru structure) • HANDLE packages @ attach locations (discrete positions) • FASTEN packages to existing structure • ALIGN packages to structure	SPS Packages Installers (SPI) (solar cells, solar concentrators, switch gears, pointing computer) • Receive packaged elements • Align for layout • Prepare surface for mounting • Layout packages • Check alignment • Fasten to structure • Make connection to next unit • Perform subelement performance check	Assumes a Mobile Truss Configuration • Fabricate on-orbit or launch from ground • Transport from fabrication facility to SPS construction site • Existing structure with rails or cables • Communications link • Align and place on rails • Operational checkout • Resupply packages • Maintenance and repair • Relocate on structure
VIA. ROTARY JOINT DRIVE SYSTEM & POWER TRANSFER MECHANISM	• TRANSPORT equipment to rotary joint location (over or thru existing extensile structure) • HANDLE equipment into position in structure • FASTEN pieces to and within structure	Transport to Assembly Site • Transporter (FF or attached) • Special manipulator for equipment handling/fastening (may require manned assistance)	Transport from Launch Vehicle to Construction Site • Transport vehicle (FF or attached) • Manipulator setup maintenance • Manned vehicle with manipulators (if required)
VII. SUBARRAYS (MPTS)	• TRANSPORT subarrays to MPTS surface (over structure) • HANDLE subarrays at attach locations (7854) • FASTEN subarrays to secondary structures (3 point, mechanical)	MPTS Subarrays Installer • Transporter (FF and attached-to-structure) • Multiple mobile manipulators for handling/fastening (manned assistance may be required)	Transport from Fabrication Facility to MPTS Surface • Transport vehicles - FF and attached • Rail/track system setup, maintenance and repair • Docking facilities • Manned vehicle with manipulators (if required)

Table 3.5.2-4 Boeing Thermal SPS Elements and Support Requirements

SPS ELEMENTS	CONSTRUCTION FUNCTION	POTENTIAL CONSTRUCTION EQUIPMENT	SUPPORT REQUIREMENTS
I. TRIANGULAR BEAMS - Spinal Trusses - Radiator Frames - SC Reflector Framework - SC Support Strut and Cross Trusses - Extension Structure (MPTS)	• HANDLE beams to assemble structure (or TRANSPORT for long - 4km trusses) • ALIGN trusses (PCS power bus only) relative to PCS • FASTEN beams together (butt weld all except MPTS extension structure - probe and drogue with external torque) • ADJUST truss lengths or beam end fittings as required	Beam and Beam Assembly Transporter • Receive beams • Beam holddowns • Beam release Beam Handler • Beam translation • Position for alignment • Adjust after fastened Beam Fastener • Fasten beams • Adjust beams	Mobile Beam Transporter (on Structure) • Assemble on orbit or launch from ground • Transport to structure • Placement on rails or cables • Communications link • Electrical power recharge • Operational checkout • Maintenance and repair Fixed Base Manipulators • Assemble on orbit or launch from ground • Transport to construction site • Alignment for mounting • Fasten to construction facility • Service and repair Small Highly Dexterous Manipulator which Travels on Long Beam • Launched from ground • Transport to construction site • Interface with fixed base manipulator • Storage port on CF • Maintenance and repair
II. FACILITIES/LARGE MODULES - Facility Manipulators - Orbit Transfer System (LEO to GEO) - Construction Facilities - Beam Builders - SPS Modules	• TRANSPORT beam builders to CFs (if not transported with CFs) • HANDLE modules/facilities for capture/docking • ALIGN modules/CFs in 2 planes; beam builders in CFs (if required) • FASTEN modules/internal beams to existing structure • ADJUST struts as required • MONITOR engagement/alignment of CFs, modules	Orbital Transfer Vehicle • Vehicle docking • Stabilization and maneuvering • On orbit propellant resupply Beam Builders • Fabricate (10 meter) triangular beams • Material forming • Material curing • Fastening cross-members • Beam alignment • Manned or unmanned Preamsembled CF Sections • Section joining interfaces • Self-aligning aids • Erectable structure	Free Flying LEO to GEO Transport • Compatible docking ports • Number and location of ports • Communications link with both LEO and ground Mount Beam Builders onto Construction Jig • Transport to construction site • Docking or EE grip interface • Position alignment for mounting • Fasten to construction facility • Checkout operations • Raw material handling • Resupply consumables • Maintenance Connect Sections to Structure Start Points • Transfer section to connection point • End effector interface • Connection alignment • Aid in deployment of erectable structures
III. CABLES - SC Tension Cables (~200) - MPTS Radial Cables (~180)	• TRANSPORT (radial cables only) (probably on reels) to MPTS construction site • HANDLE cables between and @ attach points • FASTEN cable ends - probe and drogue with external torque • ADJUST cables to position SC structure or MPTS frames	Cable Reel Transporters • Dock to reel stowage facility • Receive reels from stowage • Reel holddowns • Transport between stowage and use points • Dock to SPS work site • Release reels Cable Reel Dispenser Mechanism • Receive full reels/remove spent reels • Cable feed • Cable connection to other cables • Provide cable tension • Cable cutter • Cable fastened to structure	Transport Cable Reels to MPTS Use Points • Compatible docking ports • Load reels onto transporter • Transfer reels to cable dispenser Installation of Cable Dispenser at Use Point • Release holddown fastener • Transfer to new-use location • Position for fastening • Check alignment • Fasten to structure • System checkout • Maintenance Cable Installation • Cable stringer

Table 3.5.2-4 (Continued)

SPS ELEMENTS	CONSTRUCTION FUNCTION	POTENTIAL CONSTRUCTION EQUIPMENT	SUPPORT REQUIREMENTS
IV. <u>ELECTRICAL CONDUCTORS</u> - Between SCs and MPTS Joints (4) - From Power Conversion Equipment to Switch Gears (16) - Over Joint Buses - From Switch Gears to Distribution Points on MPTS (1000) - Between Subarrays - Reflector Control Circuitry (1500) - Bus Bar Connections - Bus Bar Harness	• <u>TRANSPORT</u> conductors (possibly on reels) to attach locations (over, on or thru existing structure) • <u>HANDLE</u> conductors between and @ attach points • <u>FASTEN</u> @ ends - connector or QD requiring external torque or simultaneous automatic latching @ both ends (7000) • <u>CHECKOUT</u> electrical continuity	<u>Electrical Conductor Reel Transporter</u> • Dock to reel stowage facility • Receive reels from stowage • Reel holdowns • Transport between stowage and use points • Dock to SPS work site • Release reels <u>Electrical Conductor Installer</u> • Receive full reels/remove spent reels • Conductor feed control • Conductor routing • Fasten conductor to structure • Conductor cutter • Conductor connector	Transport Conductor Reels to Point of Use • Compatible docking ports • Load reels onto transporter • Transfer reels to conductor installer Routing Conductors on Structure • Reel handling mechanism • Mobility capability on structure surface (or internal) • Electrical recharge • Stowage port for non-use times • Consumable parts resupply • Maintenance and repair
V. <u>PREASSEMBLED STRUCTURES</u> - SC Framework Secondary Structure - Radiator Segments - SC Support Base Structure - MPTS Secondary Structures - MPTS Frames	• <u>TRANSPORT</u> structures to installation site (over or around) • <u>HANDLE</u> structures/segments for assembly • <u>FASTEN</u> together and to existing structure (multiple point attach - latch or weld)	<u>Assembled Structures Transporter (FF)</u> • Grip structure (on CG) • Maneuver structure • Transport structure to SPS assembly site • Release structure to handling equipment • For gross alignment, use as handling equipment <u>Structure Attached Transporter</u> • Move on rails or cables • Handling structures • Aligning structures (gross)	Transport Assembled Structures to Remote Assembly Sites • Compatible handling interface • Docking ports • Services, power, propellants, etc • Collision avoidance SPS structure • Maintenance and repair Transport SPS Elements on SPS Structure • Transport platform • Existing structure with rails or cables • Communications link • Power source (outlets) • Fabricate unit • Transport unit to SPS site • Position on rails or other • Operational checkout • SPS elements resupply • Maintenance and repair • Relocate on structure
VA. <u>CAVITY ABSORBER SHELL</u> - 400 20 x 29 m Sections	• <u>TRANSPORT</u> panel sections • <u>HANDLE</u> sections for assembly attachment • <u>FASTEN</u> panel edges and helium lines	<u>Thermal Collector Installers</u> • Large transporter (FF) • Manipulators for handling • Fastening automatic and manned assisted	Transport and Install Sections onto Cavity Shell • Long reach manipulators • Docking facilities • Manned vehicle (FF) to assist fastening • Fluid servicing capability (liquid metal) • Maintenance and repair
VI. <u>PREASSEMBLED PACKAGES</u> - PCS Stanchions - Switch Gears (16) - Pointing Computer	• <u>TRANSPORT</u> packages to installation location • <u>HANDLE</u> packages for attachment to structure • <u>FASTEN</u> packages to structure (mechanical latches on preinstalled pads)	<u>PSP Installers</u> • Transporter capable of FF or transfer on or thru existing structure • Mobile manipulators capable of handling packages in confined volume • Fastening automatic • Alignment and checkout	Assumed Vehicle Capable of Travel On/Thru Existing Structure and also Free Flying • Fabrication on orbit or launch from ground • Transport from fabrication facility to SPS construction site • Existing structure with rails or cables and also docking ports • Communications link • Align and place on rails • Operational checkout • Resupply packages • Maintenance and repair • Relocate on structure

Table 3.5.2-4 (Concluded)

SPS ELEMENTS	CONSTRUCTION FUNCTION	POTENTIAL CONSTRUCTION EQUIPMENT	SUPPORT REQUIREMENTS
VI.A. TURBO-GENERATOR SETS - 20 x 29 x 5m 64	- TRANSPORT packages to cavity absorber shell - HANDLE packages for attachment to shell - FASTEN to shell panels (mechanical) and connect helium lines	Generator Set Transporter - Receive generator sets - Holddown mechanisms - Release capability - Collision avoidance Generator Set Installer - Translate generator sets to assembly site - Alignment to structure - Make mechanical, electrical, and fluid connections - Charge systems - Checkout operation	Transport to Cavity Material Supply Depot - Compatible docking port - Receive from primary transport vehicle - Transfer to on-site manipulators Long, Mobile Base Manipulator - Construct on orbit - Mount on track - Alignment technique for automatic control - Checkout - Resupply consumables - Maintenance (leak check)
VI.B. REFLECTOR FACETS - 68,000 Facets ~30 x 30 meters	- TRANSPORT facets to SC structure (over or around existing structure) - HANDLE facets @ attach sites - FASTEN facets to SC structure - probe inserted into steering mechanism receptacle (accessibility/visibility problems)	Facet Transporter - Receive facets from on orbit facility or from a primary transport vehicle - Transport facets to SPS work site - Interface with structure for purpose of supply depot Facet Installer - Receive packaged elements - Align for layout - Prepare surface for mounting - Layout packages - Check alignment - Fasten pointing device - Perform subelement performance check	Transport Facets to the Solar Concentrator Frame - Compatible docking ports. - Load reels onto transporter - Transfer reels to facet installer or stowage Number of Facets Indicates an Automated Operation such as a Traveling Truss - Fabricate on orbit or launch from ground - Transport from fabrication facility to SPS construction site - Existing structure with rails or cables - Communications link - Align and place on rails - Operational checkout - Resupply packages - Maintenance and repair - Relocate on structure
VI.C. ROTARY TRANSFORMER ASSEMBLY (RTA)/POWER CONVERSION EQUIPMENT	- TRANSPORT to attach location - HANDLE equipment at attach location - FASTEN (mechanically) equipment to and within existing structure	Same as VI.A.	
VII. SUBARRAYS - MPTS	- TRANSPORT subarrays to MPTS surface (over structure) - HANDLE subarrays at attach locations (7854) - FASTEN subarrays to secondary structures (3-point mechanical)	MPTS Subarrays Installer (in general same for all configs.) - Transporter (FF and attached) - Mobile manipulators working on existing structure - Fastening automatic; may require manned assist	Transport and Install at MPTS Work Site - Transport vehicle (FF & attached) - Rail/track system setup, maintenance - Manipulator setup, maintenance - Manned vehicle (FF or attached) to assist fastening

4.0 OCSE CONCEPT DEFINITION

4.1 Part II Objectives

Having identified in Part I the support requirements for each SPS configuration, the objective of Part II was to generate OCSE concepts which are technically feasible and programmatically viable. This was accomplished by defining potential OCSE to fulfill the specific requirements for each SPS, considering commonality aspects within and across configurations, and performing a high level screening of the OCSE candidates to identify the more significant items. Figure 4.1-1 shows the approach utilized in Part II, and the following paragraphs describe the individual tasks in more detail.

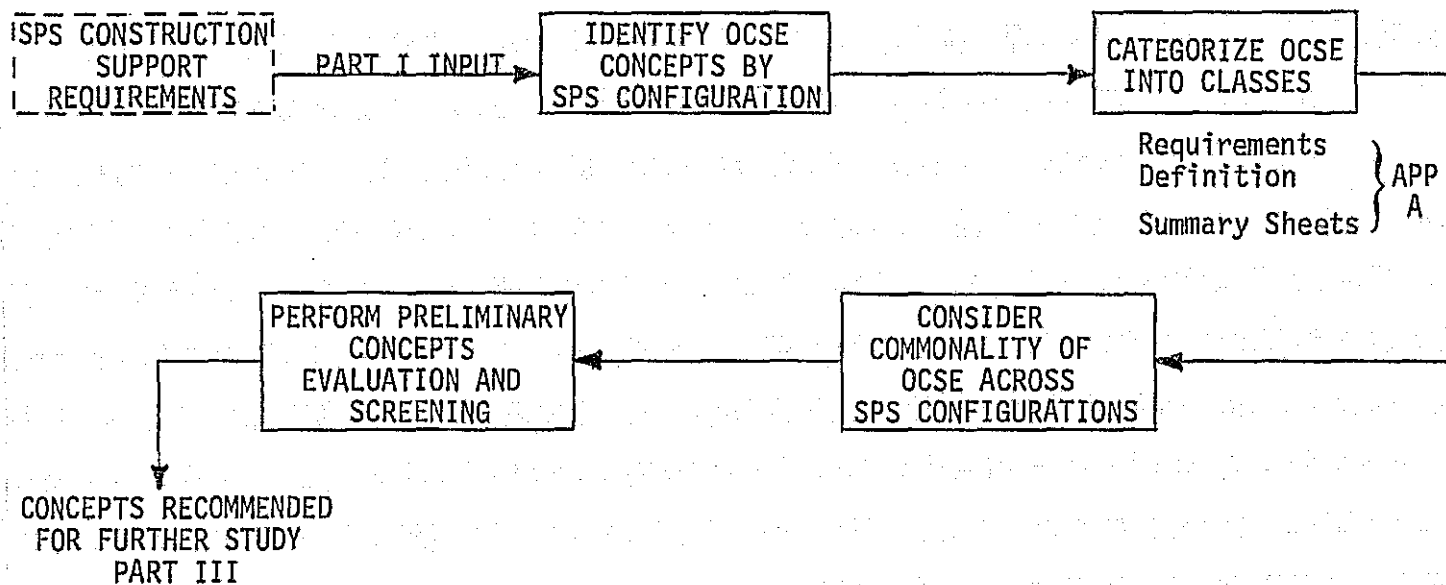


Figure 4.1-1 Part II Functional Flow

4.2 OCSE Concept Development

4.2.1 General

The purpose of this task was to identify and develop OCSE concepts with present or future application to construction of large earth orbiting systems. The approach used depended on a three step sequence: (1) prepare an inventory of potential OCSE candidates; (2) assess the use of these OCSE requirements; and (3) conceive new or improved OCSE to fill voids indicated by OCSE requirements.

An OCSE category tree was generated to ensure that an orderly approach was used in evaluating the applicability of different candidate concepts. This structured grouping, as shown in Figure 4.2.1-1, provided a quick visual reference of candidate similarities by system characteristics such as operational utility, functional capability, and hardware utilization. The primary advantages of this approach are that it provides the capability to represent similar types of hardware by one or more units, provides a single thread traceability from their original source through to final disposition, along with supporting rationale, and provides a road map by which new concepts identified in later study efforts could be grouped, analyzed, and evaluated on a comparable basis.

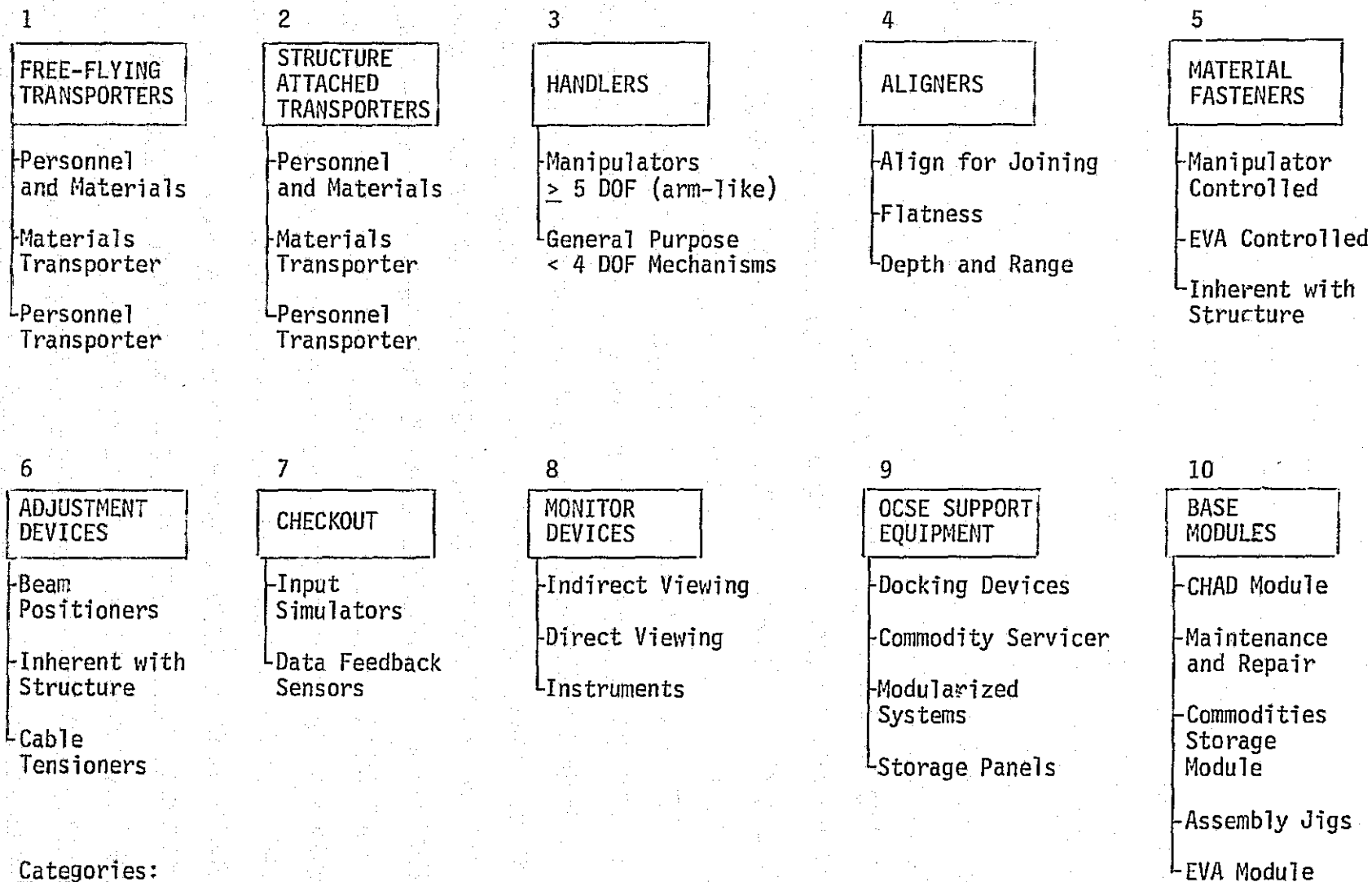
The initial data collected resulted from a search for typical support equipment items in 1) the listings of flight-qualified hardware from previous space programs; 2) system definitions developed for STS supporting research and technology programs related to Shuttle/Orbiter, Space Station, Solar Power Satellites, etc; and 3) commercial equipment used on ground based construction projects with potential applications to space construction operations.

Since many of the OCSE requirements were not satisfied by either modified or existing equipment, new OCSE was defined. Conceptual definitions were developed for new and modified equipment which included configurations, interfaces, performance, operations requirements, and impacts on interfacing elements.

Appendix A contains details of the OCSE concepts generated in the form of summary sheets. An OCSE requirements definition is also provided for each of the subcategories listed in Figure 4.2.1-1. Each concept summary sheet in the Appendix is correlated with the groups and categories shown in the table.

4.2.2 Identification of OCSE by SPS Configuration

The primary task in Part II was the identification and classification of OCSE (in functional terms) which satisfy the support requirements defined in Part I. Tables 4.2.2-1, 4.2.2-2 and 4.2.2-3 present that data for each of the SPS configurations. The support requirements are listed for each SPS element group (defined in paragraph 3.5.1), and the corresponding potential OCSE is identified. The major design drivers for each piece of OCSE are also



Categories:

A - Flight Existing C - Commercial (One "G")
 B - Flight Proposed D - New Concept
 See Appendix A

Figure 4.2.1-1 OCSE Inventory Tree

Table 4.2.2-1 OCSE for Column/Cable SPS

SPS ELE GRP NO.	SUPPORT REQUIREMENTS	POTENTIAL OCSE	MAJOR DESIGN DRIVERS	OCSE COMMON USAGE CLASSIFICATION
I. <				

Table 4.2.2-1 (Continued)

SPS ELE GRP NO.	SUPPORT REQUIREMENTS	POTENTIAL OCSE	MAJOR DESIGN DRIVERS	OCSE COMMON USAGE CLASSIFICATION
IV. ELECTRICAL CONDUCTORS	- Transport Conductor Reels to Point of Use - Compatible docking ports - Load reels onto transporter - Transfer reels to conductor installer - Collision avoidance capability - Routing Conductors on Structure - Reel handling mechanism - Mobility capability on structure surface (or internal) - Electrical recharge - Stowage port for nonuse times - Consumable parts resupply - Maintenance and repair - Connector torques	- Use Common Package Transporter - Universal Docking Mechanism - Logistics Facility Manipulator - OR Manipulator on Transporter - Guidance System - Automated CE Function - Cable Transporter (manned) - Selected Recharge Points - Stow on Tension Cables - Mobile Trans. on Main Beams - Manned System EVA/ECWS - Special EVA Hand Tool	- Logistics and distance 14 km - Transporter size 20 m mobile manipulator - Access to conductor reel receiver - Light system or rail pattern - Size and distance reel trans. - Spider concept (JSC) - Battery weight vs distance - Max. cable span of 2030 m - Transfer from beam to EVC - Spider concept (JSC) - Torque requirements	- FF Trnspr, Small - Univ Dock Device, Small - Fixed Base Manip, Small - Fixed Base Manip, Small - TV & Lighting System - Cable Att Trnspr, Cat. A - Elect. Pwr Supply Sys - General OCSE Stowage - Struct Att Trnspr Cat. A - Cable Att Cat. A - EVA Hand Tool Group
V. PREASSEMBLED STRUCTURES (MPTS)	- Transport MPTS Structure to Assembly Site - Compatible handling interface - Docking port - Services, power, propellants, etc - Collision avoidance SPS structure - Maintenance and repair - Transport SPS Elements on SPS Structure - Transport platform - Existing structure with rails or cables - Communications link - Power source (outlets) - Transport unit to SPS site - Position on rails or other - Operational checkout - SPS elements resupply - Maintenance and repair - Relocate on structure	- Strap-on Maneuvering Unit - Universal Docking Mechanism - FF Services Module - Remote Control by Crew - Dedicated Maintenance Vehicle or EVA/ECWS - Attached Transporter - Rails or Cables on Main Beams - Strap-on Communication Sys - Selected Power Recharge Points - FF Transport Vehicle - Manipulator at Facility - Use Existing Operating Mode - Transporter Loading Manip. - Maintenance by EVA/ECWS - Requires Large Manipulator	- Mounting locations and techniques - Transporter Size - Fluids and power - Vision system or preprogrammed - Crew capability and availability - Cover up to 29 km - Interference by CE - Distance of 30 km - Power supply tradeoffs - Distance 30 km 100 m fixed base manipulator - Operational functions 20 m mobile manipulator - Crew availability - Function of where and why	- Modular GN&C System - Universal Dock Device - FF Servicing Module - TV and Lighting System - FF Manned Vehicle - Mobile transporter (medium) - Rail/Cable Installer - Modular Comm System - Elect. Pwr Supply Mod. - FF Trnspr, Medium - Fixed Base Manip, Med. - TV and Lighting System - FF Manned Vehicle - Fixed Base Manip, Med.
VI. PREASSEMBLED PACKAGES	- Transport Packages to Work Site - Compatible docking port - Package loading device - Transfer packages to railed transporter or installer - Assumes packages are deployed from main beam as unit is built - Potential internal location of structure - Mount many SPI units on main beam - Communications link - Align and place on cables - Operational checkout - Resupply packages to SPI - Maintenance and repair - Relocate on new SPS structure	- Transporter (FF or attached) to carry packages from LF to work site - Dexterous manipulator to handle packages--remove from transporter, reach thru structure and place package at working location - System to move manipulator to other discrete locations - Strap-on Communications Sys - Fixed Base Fac. Manip. - Dedicated Maint. Facility and EVA - FF Transport Vehicles	- Up to 21 km FF, 29 km attached - Manipulator length 75 m, reaching thru existing structure--attachment system incorporates aligning, fastening and subelement checkout - Distance and interference - Package size and translate distance - Crew productivity and avail. - km to new site	- Univ Dock Device, Med. - Fixed Base Manip, Med. - Fixed Base Manip, Small - Modular Comm System - Structure Attached Trnspr, Manned Cat. H on - Fixed Base Manip Cat. III - Attached Trnspr. Crew - Fixed Base Manip, Med.
VIA JOINT (MPTS/SECS)	- Transport from Launch Vehicle to Construction Site - Transport vehicle (FF or attached) - Manipulator setup maintenance - Manned vehicle with manipulators (if required)	- Launch Assembled from Ground - Single or Multiple Transporters - Existing or Mobile Manip. - Manipulator Attached Cherry Picker	- May be dedicated launch - Crew control for positioning - High crew EVA involvement - Reach requirements/task dexterity	- FF Trnspr, Small - Modular Thruster Package - Fixed Base Manip, Med. - Manned Module, Cat. II - Attached to Fixed Base Boom

Table 4.2.2-1 (Concluded)

SPS ELE GRP NO.	SUPPORT REQUIREMENTS	POTENTIAL OCSE	MAJOR DESIGN DRIVERS	OCSE COMMON USAGE CLASSIFICATION
VII. SUBARRAYS (MPTS)	Transport from Fabrication Facility to MPTS Surface • Transport vehicles - FF and attached • Rail/track system setup, maintenance and repair • Docking facilities • Manned vehicle with manipulators (if required) • Maintenance and repair	Subarray Transporter (LF to site) Manipulator to remove Subarrays from Transporter and place in Automatic Installer Docking Facility (top of MPTS central hub) for Transporter Rail/track System or Mobile Manipulator to bring Subarrays onto MPTS Surface Automatic Installer may require Manned Assistance	Distance 21 km FF, 29 km attached; 40 subarrays make 10 x 10 x 10 m package - requires 200 trips Manipulator reach 10 to 25 meters Holddown for surface mover automatic Installer maintenance compatible with EVA/ELMS	FF Trnsprtr, Large Cat. M Rail/Cable Installer Univ Docking Device Cherry Picker Att Transporter Cat. D

Table 4.2.2-2 OCSE for Truss Type SPS

SPS Element Group No.	SUPPORT REQUIREMENTS	POTENTIAL OCSE	MAJOR DESIGN DRIVERS	OCSE COMMON USAGE CLASSIFICATION
I. TRIANGULAR BEAMS	Mobile Beam Transporter (on Structure) • Assemble on-orbit or launch from ground • Transport to structure • Placement on rails or cables • Communications link • Electrical power recharge • Operational checkout • Maintenance and repair Fixed Base Manipulators • Assemble on-orbit or launch from ground • Transport to construction site • Alignment for mounting • Fasten to construction facility • Service and repair Small Highly Dexterous Manipulator • Launched from ground • Transport to construction site • Interface with fixed base manipulator • Storage port on CF • Maintenance and repair	Launch from ground Transporter, free-flying Facility manipulator/TV and lights Antenna module Small 3 DOF manipulator TV and lights or instruments Railed EVA work platform Launch from ground Transporter, free-flyer Facility manipulator/TV and lights Small manipulator/EVA Small manipulator/EVA Receive from launch vehicle Transporter, free-flyer Manipulator end effector stowage Small unmanned FF or EVA	Designed to fit within HLLV Man-in-the-loop control Man-remote control Replaceable module, function of distance Battery storage or recharge stops Motion, current, force Replaceable modules Erectable structure Size Prepared surface on jig EOTS size, cherry picker EOTS size, cherry picker Small free-flyer, EOTS size Interchangeable E.E. Replaceable modules	Universal docking device FF Trnspr (700 lb, Cat. G) Antenna mod., 10 Km range Battery Recharge Station TV & Lighting System Common Replacement Modules Free-Flying Transporter (700 lb, Cat. G) One man cherry picker One man cherry picker FF Trnspr (700 lb, Cat. G) E.E. Storage Rack Stand module interchange rack
II. FACILITIES (LARGE MODULES)	Mount Beam Builders onto Construction Jig • Transport to construction site • Docking or EE grip interface • Position alignment for mounting • Fasten to construction facility • Checkout operations • Raw material handling • Resupply consumables • Maintenance Connect Sections Together • Transfer section to connection point • End effector interface • Connection alignment	Free flying vehicle EE grip interface (part of beam fabricator) Incorporated into beam bldr Onboard instruments Facility manipulator Hardwire umbilical Modularize design, EVA module One or more transport vehicles Common connect device Alignment aids or EVA	60 Km range Docking receptacle, dia., force Universal docking mechanism Latch and contact lights Mobile base, 30m long Fluid and elect. power Close to manned module Connector size, force Manned or unmanned	FF Trnspr (7,000 lb, Cat F) Universal Docking Device Universal Docking Device Std. Fluid & Power Conn. One man cherry picker Free-Flying Transporter One man cherry picker
III. CABLES (MPTS RADIAL CABLES)	Transport Cable Reels to MPTS Use Points • Compatible docking ports • Load reels onto transporter • Transfer reels to cable dispenser Installation of Cable Dispenser at Use Point • Release hold-down fastener • Transfer to new-use location • Position for fastening • Check alignment • Fasten to structure • System checkout • Maintenance Cable Installation • Cable stringer	Docking mechanism Stowage facility manipulator GN&C system Work site manipulator or EVA Remote control Transporter Facility manipulator TV/lighting system Tension readout EVA module Tethered EVA or EOTS	Size dia., acc., force Reel sizes Size, access, lighting, data feedback Data feedback Access Availability, size Access, viewing aids Adjustable setting Replaceable modules Collision avoidance problem with other cables	Univ. Dock. Device Small fixed base manip. GN&C module package Manipulator Cherry picker Free-flying transporter Small manipulator TV and lighting system Strain gage Cherry picker Onboard computer package

Table 4.2.2-2 (Continued)

SPS ELE GRP NO.	SUPPORT REQUIREMENTS	POTENTIAL OCSE	MAJOR DESIGN DRIVERS	OCSE COMMON USAGE CLASSIFICATION
IV.	Transport Conductor Reels to Point of Use	Universal Docking Mechanism	Vehicle size (HLLV, OTV, etc)	Universal Docking Dev.
	• Compatible docking ports	Manipulator on Transporter	Size a function of transporter configuration	Manip. Fixed Base, Small
ELECTRICAL CONDUCTORS	• Load reels onto transporter	Manipulator on Transporter		
	• Transfer reels to conductor installer	Manipulator on Transporter		
ROUTING CONDUCTORS ON STRUCTURE	Routing Conductors on Structure	Potential EVA Task	Number of cycles and access	Struct Att Trnspr Cat. H
	• Reel handling mechanism	Facility Manipulator	Simple 3 DOF, tension, feed, grip	Manip Mobile Base, Long
MOBILITY CAPABILITY ON STRUCTURE SURFACE (OR INTERNAL)	• Mobility capability on structure surface (or internal)	Mobile Conductor Connector by EVA or Conductor Installer	Requires access opt side of photovoltaic blankets	Struct Att Trnspr Cat. H
	• Electrical recharge	Power Recharge Stations	Major sys tradeoff area	Elect. Pwr Supply Mod.
STOWAGE PORT FOR NON-USE TIMES	• Stowage port for non-use times	Universal Stowage Rack	Manipulator EEs to small station	Universal Equip. Stowage Rack
	• Consumable parts resupply	Mobile Manipulator/EVA	Function of total logistics flow	Manned Manip. Cat. III
MAINTENANCE AND REPAIR	• Maintenance and repair	Dedicated Maint Vehicle/Fac and EVA/ECWS	Crew productivity and availability	Free Fly Trnspr Cat. F w/Att. Manip. Cat. VI
V.	Transport MPTS Structure to Assembly Site	Interchangeable Manipulator	Handle as is or prepared interface	FF Trnspr Cat. G, Large
	• Compatible handling interface	EE	Medium sized transporter	Universal Dock Dev, Lrg
DOCKING PORT	• Docking port	Universal Docking Mechanism	Fluids and elect power	FF Services Module
	• Services, power, propellants, etc	Free Flyer Services Module		
COLLISION AVOIDANCE SPS STRUCTURE	• Collision avoidance SPS structure	Remote Control by Crew	Visual system or preprogrammed	Indirect Viewing & Lighting Sys.
	• Maintenance and repair	Dedicated Maintenance Facility	Could be part of logistics facility	FF Trnspr Cat. F w/Att Manip Cat. VI
TRANSPORT SPS ELEMENTS ON SPS STRUCTURE	Transport SPS Elements on SPS Structure	Mobile Transporter	Material and people	FF Trnspr Cat. F
	• Transport platform	Rail and/or Cable Installer	Existing structure base	Align., TV & Light Sys
EXISTING STRUCTURE WITH RAILS OR CABLES	• Existing structure with rails or cables	Strap-on Communications Sys	20 km and interference	Modularized Comm. Module
	• Communications link	Selected bat. recharge points	Common to most OCSE	Elec Pwr Supply Module
POWER SOURCE (OUTLETS)	• Power source (outlets)	FF Transport Vehicle	Distance is function of logistics	
	• Transport unit to SPS site	Mobile Facility Manipulator	Travel distance of 5.2 km	Align., TV & Light Sys
POSITION ON RAILS OR OTHER	• Position on rails or other	Use Existing Oper Sequence	Major operating functions	Std Operating Sequence
	• Operational checkout	Manipulators	Logistics process flow	Manipulators, Common
SPS ELEMENTS RESUPPLY	• SPS elements resupply	Ded Maint Vehicle or EVA/ECWS	Crew prod. and availability	FF Trnspr Cat. F
	• Maintenance and repair	Mobile Facility Manipulator	700 m reach	Manip Mobile Base, Long
RELOCATE ON STRUCTURE	• Relocate on structure			
VI.	Assumes a Mobile Truss Configuration	Launch in Sections and Assembled On-orbit	Ground to LEO on HLLV	EVA Assembly Tools
	• Fabricate on-orbit or launch from ground	FF Transporter	Unit cg and docking interfaces	FF Transporter, Large
TRANSPORT FROM FABRICATION FACILITY TO SPS CONSTRUCTION	• Transport from fabrication facility to SPS construction	Built into Construction Facility (can also run on truss spans)	Guide technique, future use	Laser Guidance Tech.
	• Existing structure with rails or cables	Strap-on Comm System	Distance up to 20 km	Modularized Comm. Module
COMMUNICATIONS LINK	• Communications link	Mobile Transporter	Travel distance of 5.2 km	Align., TV & Light Sys
	• Align and place on rails	Existing Operational Sequence	Major operating functions	Std Operating Sequence
OPERATIONAL CHECKOUT	• Operational checkout	Mobile Transporter/Manipulator	Travel distance of 5.2 km	Manip Mobile Base, Long
	• Resupply packages	Dedicated Vehicle or EVA/ECWS	Location and failure type	Trnspr Cat. F & Man. Cat
MAINTENANCE AND REPAIR	• Maintenance and repair	Mobile Transporter/Manipulator	5.2 km travel with 600 m reach	Manip. Mobile Base, Long
	• Relocate on structure			
VII.	Transport from Launch Vehicle to Construction Site	Launch Assembled from Ground		FF Transporter, Large
	• Transport vehicle (FF or attached)	Single or Multiple Transporters	Crew control for positioning	Cat. F
ATTACHMENT OR DOCKING INTERFACE	• Attachment or docking interface	Universal Docking Mechanism	Size, cg, etc.	Universal Docking Device
	• Manipulator setup maintenance	Crew Controlled Fastener Mechanism	Interface, access, handling aids	EVA Handhold Fastener
MANIPULATOR SETUP MAINTENANCE	• Manipulator setup maintenance	Manipulator Attached Cherry Picker	Reach requirements/task dexterity	Struct Att Module Cat. J and V
	• Manned vehicle with manipulators (if required)			

Table 4.2.2-2 (Concluded)

SPS ELE GRP NO.	SUPPORT REQUIREMENTS	POTENTIAL OCSE	MAJOR DESIGN DRIVERS	OCSE COMMON USAGE CLASSIFICATION
VII SUBARRAYS (MPTS)	Transport from Fabrication Facility to MPTS Surface • Transport vehicles - FF and attached • Rail/track system setup, maintenance and repair • Docking facilities • Manned vehicle with manipulators (if required) • Maintenance and repair	Subarray Transporter (LF to MPTS Site) Rail/Track Installer with Manipulator Universal Docking Mechanism Manned Mobile Transporter with Attached Manipulators Dedicated Maintenance Vehicle or EVA/ECWS	Distance up to 29 km (typ. size: 10 x 10 x 10 m package) Transport and handle subarrays on MPTS Locations and FF vehicle size Crew productivity and availability Logistics flow, replacement module sizes	FF Trnsprtr, Large, Cat. M Rail/Cable Installer Universal Docking Dev. Struct Att Module, Cat. J and V FF Trnsprtr & Manipulators, Cat. D or Cat. V

Table 4.2.2-3 (Continued)

SPS ELE GRP NO.	SUPPORT REQUIREMENTS	POTENTIAL OCSE	MAJOR DESIGN DRIVERS	OCSE COMMON USAGE CLASSIFICATION
IV ELECTRICAL CONDUCTORS	Transport Conductor Reels to Point of Use - Compatible docking ports - Load reels onto transporter - Transfer reels to conductor installer Routing Conductors on Structure - Reel handling mechanism - Mobility capability on structure surface (or internal) - Electrical recharge - Stowage port for nonuse times - Consumable parts resupply - Maintenance and repair	Transporter: Docking Mechanism/Attach Pts Facility Manipulator Manipulator or EVA Automatic Device OR Facility or Small Manipulator Transporter, Rail or Surface influenced Battery Recharge Station Logistics Docking Port/ Attach Point Transporter, FF or Attached Small Manipulator or EVA	Transporter/payload size Reel size Access, frequency Reel size, access Beam size and span Frequency, location Schedule reel size Access, transport	FF Trnspr, Small Univ Docking Device, Sm Att Manipulator, Small Att Manipulator, Small Att Trnspr, Cat. K/L Elect Pwr Supply Mod. OCSE Stowage Panel Att Trnspr, Cat. M Att Trnspr, Cat. K/L
V. PREASSEMBLED STRUCTURES	Transport Assembled Structures to Remote Assembly Sites - Compatible handling interface - Docking ports - Services, power, proplants, etc - Collision avoidance SPS structure - Maintenance and repair Transport SPS Elements on SPS Structure - Transport platform - Existing structure with rails or cables - Communications link - Power source (outlets) - Fabricate unit - Transport unit to SPS site - Position on rails or other - Operational checkout - SPS elements resupply - Maintenance and repair - Relocate on structure	Free-flying Transporter: Structures EE Interface Docking Mechanism/Attach Pt Part of Transporter Systems Inherent in Transporter Systems Service Vehicle (ECHS) or Return-to-Base Attached transport platform/boom Rail or Cable Installer Antenna Module, Part of Platform Battery Recharge or Power Outlet Station Manipulators in MF-1 or On-site Free flying Transporter, if needed Manipulator Remote/Visual Attached Material Transporter Manipulator or EVA Manipulator/Transporter	Structure attach point Facility design Distances, cargo mass Geometric configuration of route Distance Platform size Temp. or permanent Distance of 5 km Frequency location Platform design Section sizes Platform section sizes Data Schedule, element size Replaceable modules, ECHS Platform size	FF Trnspr, Medium Std EE Grip Inter. Univ Docking Device FF Servicing Vehicle Radar Coll Avoid Sys FF Trnspr, Cat. F Att Base Long Boom Use Boom for Rails Base Modular Comm Sys Elect Pwr Supply Mod. FF Trnspr, Sm, Cat. F FF Trnspr, Medium Fixed Base Manip, Long Data Att Transporter Cat. M Att Trnspr, Cat. K/L Att Base Long Boom
VA. CAVITY ABSORBER SHELL	Transport and Install Sections onto Cavity Shell - Long reach manipulators - Docking facilities - Manned vehicle (FF) to assist fastening - Fluid servicing capability (liquid metal) - Maintenance and repair	Transporter (Large): Long Manipulator/Boom Docking Mechanism/Attach Pt ECHS - dexterity ECHS ECHS	Shell section sizes Section interface Access Safety, dexterity Replaceable modules	FF Trnspr Cat. G Fixed Base Long Boom Univ Docking Device, Sm Cherry Picker Cherry Picker Cherry Picker
VI. PREASSEMBLED PACKAGES	Assumed Vehicle Capable of Travel On/Thru Existing Structure and also Free flying - Fabrication on orbit or launch from ground - Transport from fabrication facility to SPS construction site - Existing structure with rails or cables and also docking ports - Communications link - Align and place on rails - Operational checkout - Resupply packages - Maintenance and repair - Relocate on structure	Launch from ground FF and Attached Transporter Attached or Surface-influenced Vehicle Part of Transporter Manipulator/Visual Remote/Visual N/A Manipulator or EVA Transporter/Manipulator	In HLLV Structure interference, avoidance Beam size, path Self-alignment device Operational functions Crew productivity Vehicle size, frequency of relocation	Fixed Base Manip, Small FF Trnspr, Small Att Trnspr, Cat. M Modular Comm Sys TV & Lighting Sys TV & Lighting Sys Att Transporter, Cat K/L Fixed Base Manip, Large

Table 4.2.2-3 (Concluded)

SPS ELE GRP NO.	SUPPORT REQUIREMENTS	POTENTIAL OCSE	MAJOR DESIGN DRIVERS	OCSE COMMON USAGE CLASSIFICATION
VIA.	Transport to Cavity Material Supply Depot - Compatible docking port - Receive from primary transport vehicle - Transfer to on-site manipulators Long, Mobile Base Manipulator - Construct on orbit - Mount on track - Alignment technique for automatic control - Checkout - Resupply consumables - Maintenance (leak check)	Transporter Free-flyer: Docking Mechanism, Attach Pt Manipulator Manipulator Manipulators plus EVA Large Manipulator Remote/Visual Transporter/Manipulator EVA or Remote Sensors	No. of ports/points, schedules Turbo-generator set size, mass Turbo-generator set size, mass Generator set installer design Piece size Data Package size schedule ECWS/Data	FF Trnsprtr, Medium Univ Docking Device Att Manipulator, Short Att Manipulator, Short FF Trnsprtr, Cat. D-F Fixed Base Manip, Med. TV & Lighting System Cherry Picker
VIB.	Transport Facets to the Solar Concentrator Frame - Compatible docking ports - Load onto transporter - Transfer to facet installer or stowage Number of Facets Indicates an Automated Operation such as a Traveling Truss - Fabricate on orbit or launch from ground - Transport from fabrication facility to SPS construction site - Existing structure with rails or cables - Communications link - Align and place on rails - Operational checkout - Resupply packages - Maintenance and repair - Relocate on structure	Docking Mechanism or Attach Point Manipulator Transport Pieces Fabricate On-orbit, Manipulators plus EVA Assemble On Site (Option 2) Part of Truss System Manipulator, Automatic Latches/Align Remote/Visual Transporter, attached Manipulator, EVA Transporter/Manipulator	No. of ports/points required Facet package size, number Truss size, no. of pieces Beam size, Temp or Perm. Alignment accuracy Data Resupply packages, size ECWS Truss size	FF Trnsprtr, Medium Univ Docking Device Att Manipulator, Short Att Manipulator, Short FF Transporter, Cat D-F Fixed Base Manip, Med. Rail/Cable Installer Modular Comm Sys. TV & Lighting Sys TV & Lighting Sys Att Trnsprtr, Cat. D Fixed Base Manip, Med.
VII.	Transport and Install at MPTS Work Site - Transport vehicle (FF and attached) - Rail/track system setup, maintenance - Manipulator setup - Manned vehicle (FF or attached) to assist fastening - Maintenance and Repair	Free flying Transporter Manipulator Manipulator ECWS Dedicated Maintenance Vehicle or EVA/ECWS	Subarrays installer size Installer design Logistics flow, replacement Module Sizes	FF Trnsprtr, Cat. M Univ Docking Device Rail/Cable Installer Att Base Rot. Boom Cherry Picker FF Trnsprtr, Cat. D & Manipulator Cat. V

listed. Finally, an attempt was made to classify the OCSE by using brief, common labels for similar pieces of OCSE. Due to the various combinations possible for transporters and handlers, a separate matrix was developed for these processes. Each area was divided into categories with specific characteristics, which are defined in Table 4.2.2-4.

4.2.3 OCSE Summary List

The OCSE lists generated for each SPS configuration contain, as inspection of those lists indicate, items which are common to all the configurations, or to two of the three configurations. Table 4.2.3-1 summarizes the types of OCSE required in the SPSs, and Figure 4.2.3-1 shows some of the major concept alternatives as they apply to the OCSE Inventory Tree established earlier. It should be noted that the OCSE complement will, for the operational system, be a subset of the concept list presented in Figure 4.2.3-1. Depending upon the actual SPS configuration, and upon trade studies of the concept alternatives, the overlapping OCSE concepts will be combined into a complete, efficient system.

Table 4.2.3-1 OCSE Summary List

- | | |
|--------------------------------------|------------------------------------|
| • Transporter, Free Flying | • Cherry Picker |
| • Transporter, Structure Attached | • Universal Storage Panel |
| • Manipulator, Mobile Base | • Modular Systems (G,N&C/Comm/ACS) |
| • Manipulator, Fixed Base | • EVA Hand Tools |
| • Long Boom, Attached Base | • Monitor, Direct Viewing |
| • Universal Docking Device | • Servicing Module |
| • Aligner (EVA, TV, Laser) | • Checkout System |
| • Fastener (EVA, Manipulator, Latch) | |

Table 4.2.2-4 OCSE Categories for Transporters and Handlers

TRANSPORTERS	Translation Mode	Transport Function	Configuration Options	Support Req/Equipment	Category
	Free Flying Vehicle o Propellant o GN&C o Communications o CDS	Personnel Mover	Open Platform	Crew Suit System EMU/MMU, man rated closed ECS, Umbilical or Tether Docking Device & Receptacle, Comp. with man	A
			Semi Open Platform	Pressurized Compartment, man rated upper half of EMU suit on Can Docking Device & receptacle, comp. with man	B
			Closed Platform	Pressurized compartment, man rated docking device & receptacle, comp. with man	C
		Materials & Personnel Mover	Open Platform	Same as Category A & provide material pallets & holddowns	D
			Semi Open Platform	Same as Category B & provide material pallets & holddowns	E
			Closed platform	Pressurized compartment, man rated docking device & receptacle, comp. with man Provide material holddowns	F
		Materials Mover	Open platform	Docking device & receptacle, unmanned Material pallets & holddowns Remote control station	G
	Structure Attached	Personnel Mover	Open Platform	Crew suit system EMU/ECNS closed ECS, umbilical or tether structure to vehicle attachment interface Crew transfer airlock, comp. with suited man	H
			Semi Open Platform	Pressurized compartment, man rated Crew transfer airlock Structure to vehicle attachment interface	I
			Closed platform	Pressurized compartment, man rated Crew transfer airlock at maintained press. structure to vehicle attachment interface	J
		Materials & Personnel Mover	Open Platform	Same as Category H plus provide material pallets and holddowns Vehicle pickup and relocation interface	K
			Closed Platform	Same as Category I plus provide material pallets and holddowns Material load and removal capability	L
		Materials Mover	Open Platform	Structure to vehicle attachment interface Area stowage locations loading and unloading parts; Vehicle pick up and relocation interface Material load and removal capability	M

Table 4.2.2-4 (Concluded)

HANDLERS	Handle Mode	Handle Function	Configuration Options	Support Req./Equipment	Category
	General Purpose Mechanism (Limited DOF ≤ 4 DOF)	Translate Personnel	Fixed end, long rotating boom	Manned module to boom interface (see attached personnel movers) Crew transfer airlock, pressurized requires man rating of long boom	I
		Translate materials	Fixed end, long rotating boom	Material transport module to boom interface (see attached material movers) Requires manned remote control Requires material loading & unloading	II
		Translate Materials & Personnel	Fixed end, long rotating boom	Multiple support capability same as Cat. I and II above Collision avoidance capability	III
			Fixed end, long telescoping and rotating boom	Limited use as translation road more complex than Cat. I, II, III Limited reach capability	IV
	Manipulators (Arm like)	Dexterious Manipulative Task	Arm similar to PFMA to Shuttle	Manned Remote Control Interchangeable end effectors Manned rated when supct, manned module Variable control accuracy Adaptable to mounting on manned/unmanned space vehicles	V
		Manipulative Task Req. High Forces & Torques	Same as above	Most likely requires two arms working together Requires 6 DOF controllers	VI

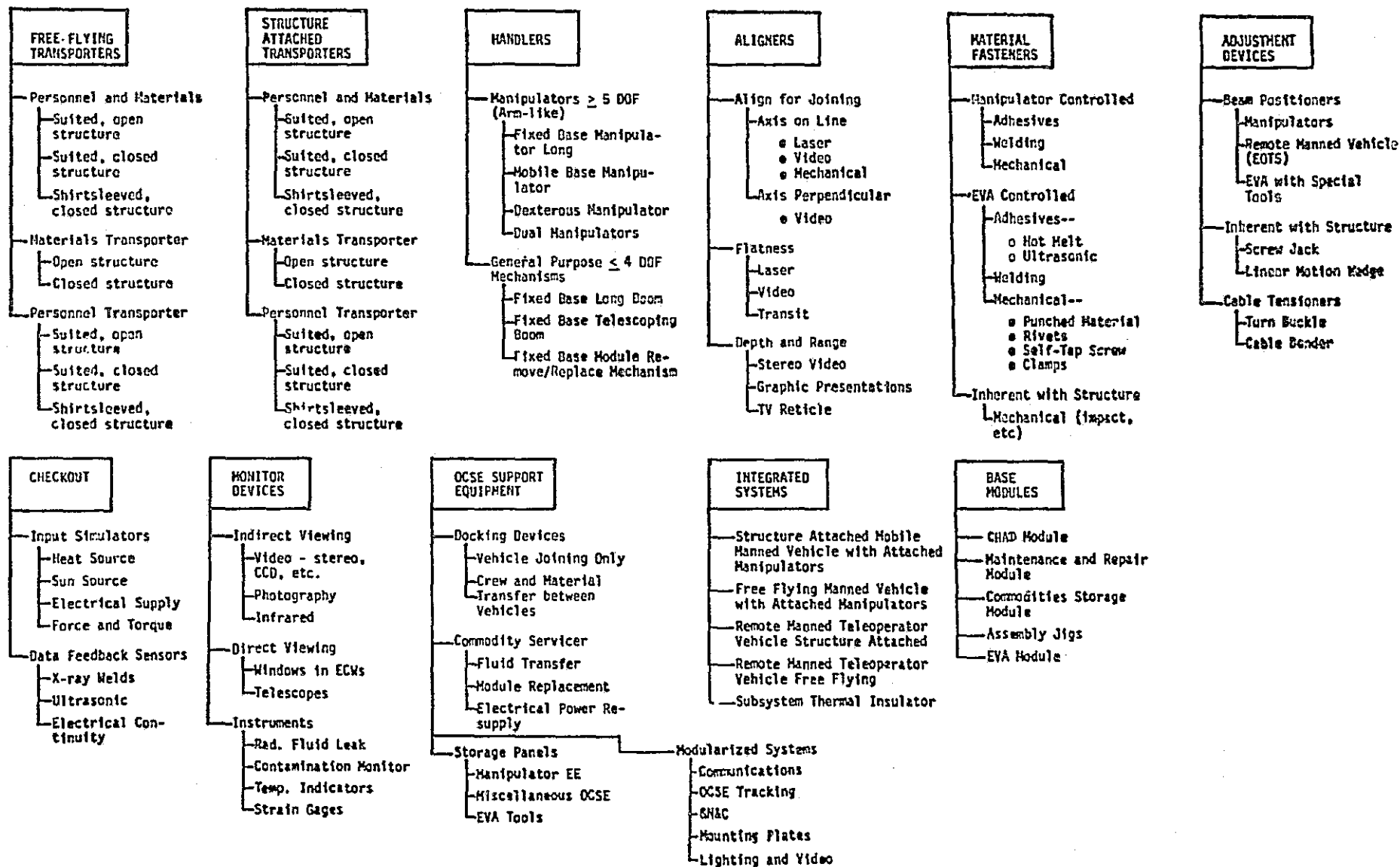


Figure 4.2.3-1 OCSE Candidate Concepts

4.3 Preliminary OCSE Concepts Screening

4.3.1 OCSE Screening Criteria Selection

A relatively large number of OCSE candidates were identified during Part II of the study. Many of the potential candidates were obviously significant to the study and required further detailed evaluation, while others were less significant in both functional and design terms. Therefore, it was necessary to reduce the number of candidates in as few steps as feasible to "filter out" less attractive solutions. The objective was to develop and work approaches to identify:

- 1) Future supporting research and technology items;
- 2) Technical feasibility of proposed equipment;
- 3) Items having a high usage probability;
- 4) Proposed OCSE development incompatibility with SPS program milestones.

Many different tradeoff parameters were evaluated which could have an impact on the decision to eliminate or retain specific OCSE concepts. Some of these were eliminated early due to having only minor effects on equipment concepts. It was important at this point to determine which factors were relevant to the screening process, and the specific type and form of data that could be used. Care was taken to identify only those meaningful parameters or ones having high relative importance. For example, during this phase no concepts were eliminated from a cost standpoint. The parameters finally selected were as follows:

- 1) Task Cycles - Is the support task performed by the OCSE done few or many times, and on a scheduled or unscheduled basis? If done many times, the support equipment required takes on greater relative importance.
- 2) Performance Flexibility - Can a number of different functional tasks be accomplished by this unit? If so, it is a reasonable candidate for more detailed analysis.
- 3) Performance Redundancy - Does this equipment perform a similar functional task as that of other equipment? If only one concept seems applicable to a particular task, that concept should be investigated further because it may be critical to SPS construction.

- 4) Size - Is the OCSE concept small, medium, or large? Size gives a measure of OCSE system complexity and affects launch transportation capabilities which gives some measure of transportation impacts. A large system may require on-orbit assembly and that task deserves additional analysis.
- 5) Development Impacts - Can any special materials, processes, and facilities involved in the development, testing, and production of such OCSE be identified? New development items may require early trade studies or design analyses.
- 6) Concept Design Anomalies - Based on past experience can design/performance factors most likely to cause trouble be identified? Such factors should receive attention early in SPS programmatic development.
- 7) Interfaces - Are there many interfaces involved with setup, operations, and maintenance? If so, they should be identified and analyzed as soon as possible.
- 8) State of the Art - Does this concept use existing technology or require new technology development? A high probability of future supporting research and technology based on past and projected SRT would result in a high priority for further study.
- 9) SRT Time-Phasing - If the OCSE requires an SRT effort, does this effort have a direct impact on schedule milestones associated with SPS program development? Such impacts must be minimized by studying the concept early in SPS program development.
- 10) Potential Obsolescence - Project and evaluate to see if significant increases in the state of the art of related technology might render specific OCSE obsolete. A high probability of obsolescence gives any OCSE concept a low priority for further study.
- 11) Adaptability to Verification on Ground - Can the OCSE concept operations verification be completed in a one-g environment by ground simulations? Does the OCSE require prototype development? If the concept can be verified by ground testing, its development should begin early enough to allow completion of such tests before STS demonstration flights.

- 12) Representative of SPS Baseline - Is the concept applicable in support of one, two, or all three of the SPS baseline configurations? Potential applicability to many (or all) SPS concepts gives the OCSE a high priority.

4.3.2 Concept Screening Process

The OCSE preliminary screening methodology used here was based on a simplified matrix approach developed as shown in Figure 4.3.2-1. The emphasis during this task was to generate an OCSE concept list organized in a descending order from the highest development priority preference. Accomplishment

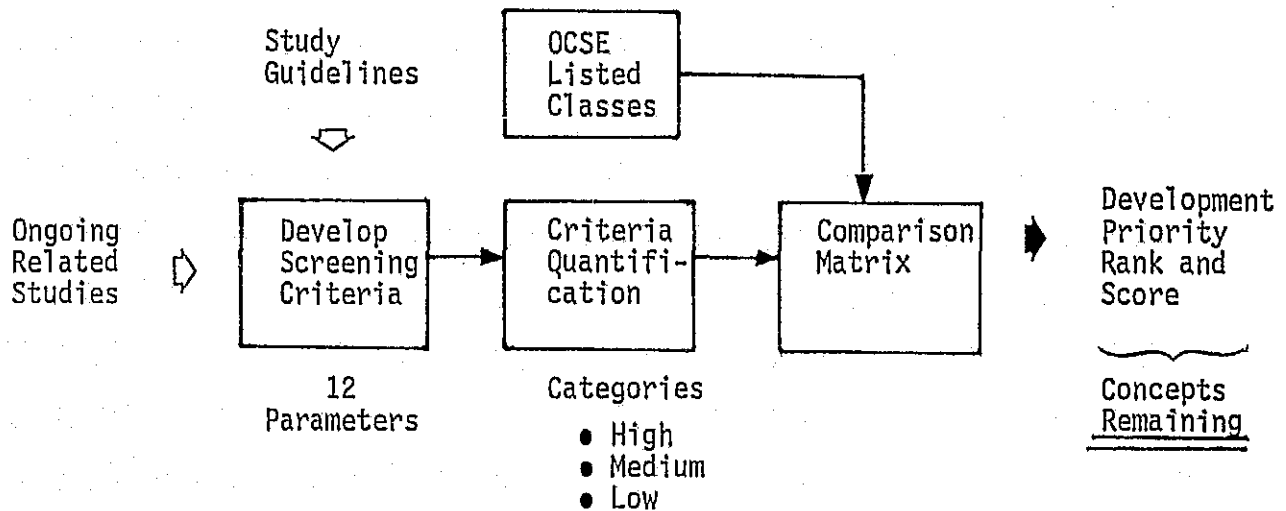


Figure 4.3.2-1 Screening Methodology Process Flow

of this list required a simple quantification process which would aid in separating the preferred concepts from the total list of proposed OCSE. Concept grading against each parameter was performed using a scale of--low (score = 0), medium (score = 1), and high (score = 2)--where high was relevant to a high priority preference for near term future development. Finer separation of categories was determined not to be justified due to the quality of the data available and the subjectivity used in assigning the parameter categories to each of the many OCSE concepts. Table 4.3.2-1 presents a summary defining the assignment of categories to the criteria parameters.

Figure 4.3.2-2 presents the complete list of OCSE items considered in the evaluation, categorized into groups. Table 4.3.2-2 shows the score received by each piece of OCSE against each of the 12 parameters. The last

Table 4.3.2-1 Priority Assignment by Categories

Categories Parameters	High	Medium	Low
Task Cycles	Many cycles	Average cycles	Few cycles
Performance Flexibility	Multifunctional/ task capabilities	Limited number of task capabilities	Dedicated task effort
Performance Redundancy	Only unit capable of doing task	Limited options capable of doing task	Many optional means of doing task
Size	Large; greater than HLLV payload envelope	Medium; assembled and launched from ground	Small; like EVA hand tools
Development Impacts	New materials, processes, or fa- cilities required	Modified processes or facilities re- quired	No new materials, processes, or fa- cilities identi- fied
Concept Design Anomalies	Operational and performance prob- lems identified	Few potential de- sign problem areas	No identifiable design anomalies
Interfaces	Complex and varied interfaces	Simple multiple interfaces	Simple mounting interface
State of the Art	Supporting re- search and tech- nology required	SRT from related technology	Existing techno- logy
SRT Time Phasing	Impacts specific SPS milestones	Minimum impact on SPS schedule	Dedicated to OCSE; no impact on SPS schedule
Potential Obsolescence	Unlikely to be- come obsolete	Moderate probabil- ity of becoming obsolete	Good probability of becoming ob- solete
Adaptability to Ground Verification	Consider system and subsystem ground simulations	Consider for sub- system ground simu- lations	Should not consider for ground verifi- cation
Represents SPS Baselines	Three configurations	Two Configurations	One Configuration

column of the table shows how each item ranked against all other items in the list, and gives the total score (addition of 0's, 1's, and 2's based on a low, medium, or high rating for each parameter) received by the OCSE item. Thus an

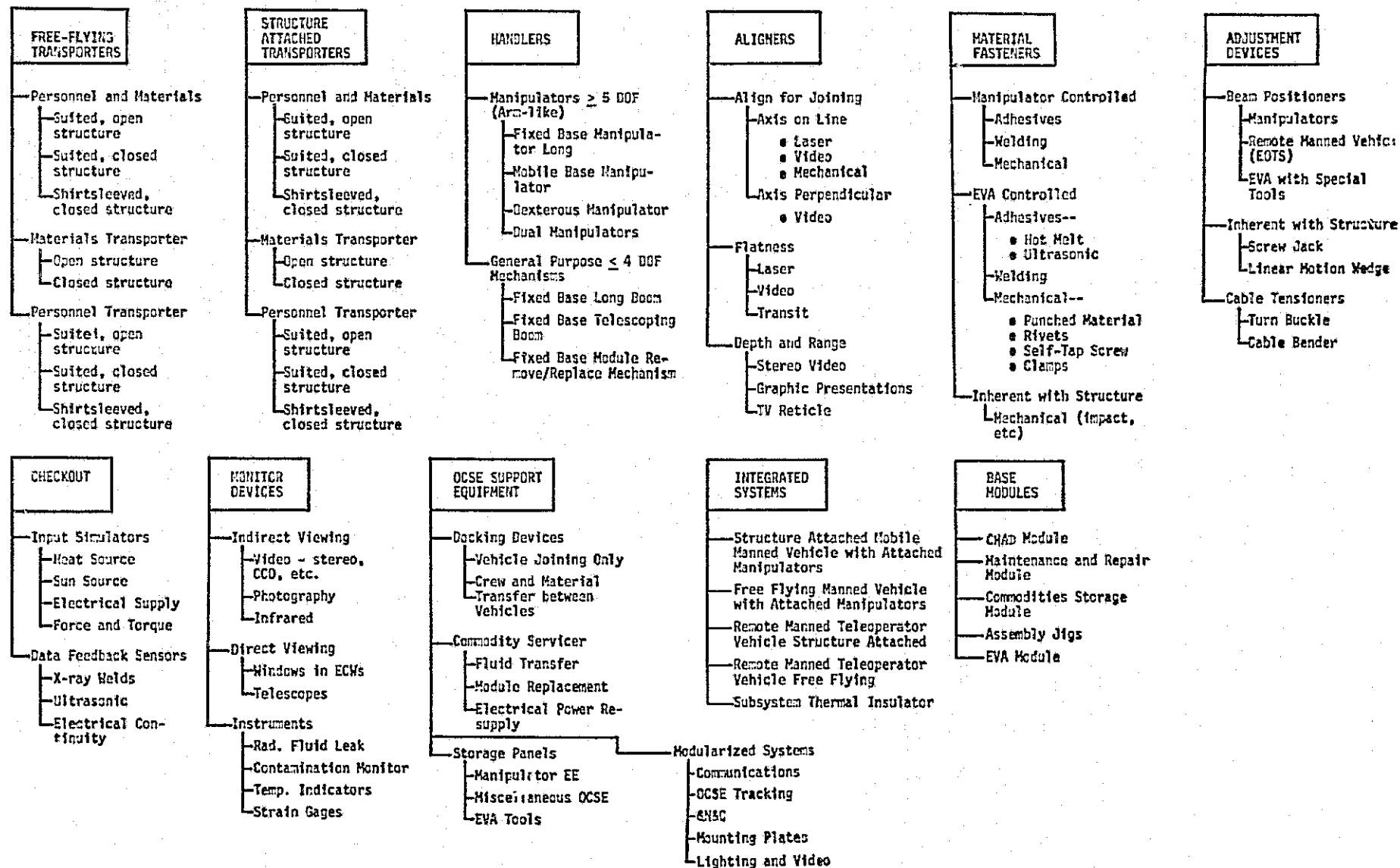


Figure 4.3.2-2 OCSE Development Preference Ranking within Groups

Table 4.6.2-2 UCSE Classes Screening Analysis Matrix

UCSE CONCEPTS	SCREENING PARAMETERS												
	TASK CYCLES	PERFORMANCE FLEXIBILITY	PERFORMANCE REDUNDANCY	SIZE	DEVELOPMENT IMPACTS	CONCEPT DESIGN ANALALIES	INTERFACES	STATE OF THE ART	SRT TIME PHASING	POTENTIAL OBSOLESCENCE	ADAPTABILITY TO GROUND VERIFICATION	REPRESENTS SPS BASELINES	NUMERICAL RANKING AND SCORE
• Base Modules													
- CMD Module	H	H	H	H	H	M	H	M	H	M	M	H	2/20
- EVA Module	H	H	M	H	M	H	H	M	H	M	M	H	5/17
- Commodities Storage Module	H	L	M	M	M	H	H	R	H	H	M	H	4/18
- Maintenance and Repair Module	M	P	H	M	H	H	H	M	M	M	H	H	4/18
- Assembly Jigs	L	L	H	H	H	M	M	H	H	M	M	L	8/14
• Transporters													
- Personnel Trnsptr Free Flying													
- Suited, Open Structure	L	H	M	M	M	L	H	L	M	H	M	H	9/13
- Suited, Closed Structure	L	H	H	M	M	L	H	L	M	H	M	H	9/13
- Shirtsleeved, Closed Struc	L	M	H	M	M	L	M	L	M	H	M	H	11/11
- Materials Trnsptr Free Flying													
- Open Structure	H	L	M	H	M	L	M	M	M	H	M	H	8/14
- Closed Structure	L	L	M	M	M	L	M	M	M	H	M	H	11/11
- Personnel and Materials Transporter Free Flying													
- Suited, Open Structure	H	H	M	M	M	L	H	L	H	M	H	H	7/15
- Suited, Closed Structure	H	H	M	M	M	L	H	L	H	M	L	H	9/13
- Shirtsleeved, Closed Struc	M	M	M	M	M	L	M	L	M	M	L	H	12/10
- Personnel Trnsptr Struc Att													
- Suited, Open Structure	L	H	M	M	M	H	H	L	H	H	M	H	7/15
- Suited, Closed Structure	L	H	M	M	M	H	H	L	H	H	M	H	7/15
- Shirtsleeved, Closed Struc	L	M	M	M	M	M	H	L	H	H	M	H	8/14
- Materials Trnsptr Struc Att													
- Open Structure	H	L	M	M	M	H	H	M	M	H	M	H	5/17
- Closed Structure	L	L	M	M	M	M	H	M	M	H	M	H	8/14
- Personnel and Materials Trnsptr													
- Suited, Open Structure	H	H	M	M	M	H	H	L	H	M	M	H	4/18
- Suited, Closed Structure	M	H	M	M	M	H	H	L	H	M	M	H	6/16
- Shirtsleeved, Closed Struc	M	M	M	M	M	M	H	L	M	M	L	H	9/13
• Handlers													
- General Purpose ≤ 4 DOF Mech													
- Fixed Base Long Boom	H	L	H	H	H	H	H	H	H	H	L	M	3/19
- Fixed Base Telescoping Boom	H	L	H	H	H	H	H	M	H	H	L	M	4/18
- Fixed Base Module Remove/ Replace Mechanism	H	M	M	M	H	H	H	M	H	H	M	H	5/17
- Manipulators ≥ 5 DOF (Armlike)													
- Fixed Base Manipulator	H	M	H	H	H	H	H	M	H	H	M	H	1/22
- Mobile Base Manipulator	H	M	H	H	H	H	H	H	H	H	M	H	1/21
- Dexterous Manipulator	H	H	M	M	M	H	H	H	H	H	M	H	3/19
- Dual Manipulators	M	H	M	M	M	H	H	M	H	H	M	H	4/18

Table 4.3.2-2 (Continued)

OCSE CONCEPTS	SCREENING PARAMETERS												
	TASK CYCLES	PERFORMANCE FLEXIBILITY	PERFORMANCE REDUNDANCY	SIZE	DEVELOPMENT IMPACTS	CONCEPT DESIGN ANOMALIES	INTERFACES	STATE OF THE ART	SPT TIME PHASING	POTENTIAL OBSCULESCENCE	ADAPTABILITY TO GROUND VERIFICATION	REPRESENTS SPS BASELINES	NUMERICAL RANKING AND SCORE
• Aligners													
- Surface Flatness Aligner													
- Video	H	H	L	L	L	L	L	L	L	H	H	H	13/9
- Laser	M	H	L	L	H	L	M	M	L	H	H	H	9/13
- Transit	M	M	L	L	M	L	M	L	L	M	H	M	14/8
- Align for Joining													
- Axis on Line													
- Laser	H	H	L	L	H	L	M	M	L	H	H	H	8/14
- Video	H	H	L	L	L	L	L	L	L	H	H	H	12/10
- Mechanical	M	M	L	L	M	L	M	L	L	H	H	H	12/10
- Axis Perpendicular													
- Video	H	H	L	L	L	L	L	L	L	H	H	H	12/10
- Depth and Range													
- Stereo Video	H	H	M	L	L	L	L	L	L	H	H	H	11/11
- TV Reticule	M	L	M	L	L	L	L	M	L	M	H	H	14/8
- Graphic Presentations	M	L	M	L	L	L	L	M	L	H	H	H	13/9
• Fasteners													
- EVA Controlled Fastener													
- Mechanical													
- Punched Material	H	L	L	L	L	L	L	L	L	M	H	H	15/7
- Rivets	H	L	L	L	L	L	L	L	L	M	H	H	15/7
- Self-Tapping Screw	H	L	L	L	L	L	L	L	L	M	H	H	15/7
- Clamps or Latches	H	L	L	L	L	M	M	L	L	M	H	H	13/9
- Adhesives													
- Hot Melt	H	L	L	L	M	M	M	M	M	M	H	H	10/12
- Ultrasonic	H	L	L	L	M	M	M	L	M	M	H	H	11/11
- Welding	H	L	M	L	M	M	M	L	M	M	H	H	10/12
- Manipulator Control Fastener													
- Mechanical	H	L	L	L	L	L	L	L	L	M	H	H	15/7
- Adhesives	H	L	L	L	M	M	M	M	M	M	H	H	10/12
- Welding	H	L	M	L	M	M	M	L	M	M	H	H	10/12
- Inherent with Structure													
- Impact Latch	M	L	L	L	L	M	L	L	L	L	H	M	17/5
- Remote Latch/Release	M	L	L	L	L	M	L	L	L	L	H	M	17/5
• Adjusters													
- Cable Tensioners													
- Turn Buckle	M	L	H	L	L	L	L	L	L	L	H	L	17/5
- Cable Bender	M	L	H	L	L	L	L	L	L	L	H	M	16/6
- Inherent with Structure													
- Screw Jack	H	L	M	L	L	M	L	L	L	L	M	M	16/6
- Linear Motion Wedge	M	L	M	L	L	M	L	L	L	L	M	M	17/5

OCSE CONCEPTS	PARAMETERS												NUMERICAL RANKING AND SCORE
	TASK CYCLES	PERFORMANCE FLEXIBILITY	PERFORMANCE REDUNDANCY	SIZE	DEVELOPMENT IMPACTS	CONCEPT DESIGN ANOMALIES	INTERFACES	STATE OF THE ART	SRT TIME PHASING	POTENTIAL OBSOLESCENCE	ADAPTABILITY TO GROUND VERIFICATION	REPRESENTS SPS BASELINES	
• Adjusters (Continued)													
- Beam Positioners													
- Manipulators	H	H	M	M	L	M	M	M	M	H	M	H	7/15
- EVA/Tools	M	H	L	L	L	L	L	M	L	M	H	H	15/9
- Remote FF Teleoperator	M	H	M	M	L	M	L	M	M	M	M	H	10/12
• Checkout Systems													
- Input Simulators for Checkout													
- Sun Source	L	L	M	L	M	M	L	M	L	L	H	H	14/8
- Heat Source	M	M	H	L	M	M	M	M	L	H	H	H	8/14
- Electrical Supply	M	L	H	L	L	L	L	L	L	H	L	H	15/7
- Force and Torque	M	L	H	L	L	L	L	L	L	M	H	L	16/6
- Data Feedback													
- Sensors for Checkout													
- X-ray Welds	H	L	H	L	L	L	L	L	L	M	H	H	15/9
- Ultrasonic	H	L	H	L	L	L	L	L	L	M	H	H	15/9
- Electrical Continuity	H	L	H	L	L	L	L	L	L	M	H	H	15/9
• Monitor Systems													
- Direct Viewing													
- Windows	H	M	L	L	L	M	L	L	L	M	H	H	13/9
- Telescopes	M	M	M	L	L	L	L	L	L	M	H	H	14/8
- Binoculars	L	M	L	L	L	L	L	L	L	L	H	H	17/5
- Indirect Viewing													
- Video-Stereo, CCD, etc	H	M	M	L	L	M	L	M	M	H	H	H	9/13
- Photography	M	H	M	L	L	L	L	L	L	H	H	H	12/10
- Infrared	M	M	M	L	L	L	L	L	L	M	H	H	14/8
- Instruments													
- Strain Gages	L	L	L	L	L	L	L	L	L	M	H	H	17/5
- Temp. Ind.	L	L	M	L	L	L	L	L	L	M	H	H	16/6
- Rad. Fluid Leak	M	L	M	L	L	M	M	M	M	H	H	H	10/12
- Auto. Sensors	M	M	M	L	L	L	L	L	L	M	H	H	14/8
- Contamination Monitor	M	L	M	L	L	M	M	M	M	H	H	H	10/12
• OCSE Support Systems													
- Docking Devices													
- Crew and Material Translate	M	M	H	M	H	H	H	M	M	M	H	H	4/18
- Vehicle Joining Only	H	H	H	M	H	M	H	M	M	M	H	H	2/20
- Commodity Servicer													
- Module Replacement	M	M	M	M	M	M	L	M	H	H	H	H	7/15
- Fluid Transfer	M	L	M	M	M	M	H	M	H	H	H	H	6/16
- Electrical Power Resupply	H	L	M	M	L	L	M	L	H	H	H	H	10/12

Table 4.3.2-2 (Concluded)

OCSE CONCEPTS	SCREENING PARAMETERS												
	TASK CYCLES	PERFORMANCE FLEXIBILITY	PERFORMANCE REDUNDANCY	SIZE	DEVELOPMENT IMPACTS	CONCEPT DESIGN ANOMALIES	INTERFACES	STATE OF THE ART	SRT TIME PHASING	POTENTIAL OBSOLESCE	ADAPTABILITY TO GROUND VERIFICATION	REPRESENTS SPS BASELINES	NUMERICAL RANKING AND SCORE
• OCSE Support Systems (Continued)													
- Storage Panels	H	M	M	M	M	M	M	M	M	H	H	H	6/16
- EVA Tools	H	M	M	L	M	M	M	M	M	M	H	H	8/14
- Manipulator EE	H	H	H	L	H	M	M	M	M	M	H	H	5/17
- Miscellaneous OCSE	M	M	M	L	M	M	M	M	M	L	H	H	10/12
- Modularized Systems													
- OCSE Tracking	H	H	M	L	M	H	M	H	M	M	H	H	5/17
- Communications	H	H	H	L	H	M	H	M	M	H	H	H	3/19
- GN&C	H	H	M	L	H	M	M	M	M	H	H	H	5/17
- Mounting Plates	H	M	M	L	M	M	M	M	M	H	H	H	7/15
- Lighting	H	M	M	L	L	L	L	M	M	H	H	H	10/12
- Video	H	M	M	L	L	M	L	M	M	H	H	H	9/13
• Integrated System Concepts													
- Subsystem Insulator													
- Sheet Insulation	H	H	M	M	M	M	M	M	M	M	H	H	6/16
- Foam Insulation	L	M	M	L	H	M	M	H	M	L	M	H	10/12
- Paint Applier	L	M	M	L	H	M	M	M	M	L	M	H	11/11
- Manned Cherr Picker													
- Free Flying with Manip Arm	H	H	M	M	M	H	H	H	M	M	M	H	4/18
- Att to Long Boom with Manipulator Arms	H	H	M	M	M	H	H	H	H	M	H	H	2/20
- Structure Attached	H	M	M	M	M	H	H	H	H	M	H	H	3/19
- Remote Manned Maintenance Vehc	H	H	M	M	M	H	M	H	H	M	M	H	4/18

entry of 8/14 means that the item ranks eighth in importance within the list, having received a total score of 14. OCSE items receiving the same score were given the same rank.

Table 4.3.2-3 lists the comparative ranking of the 64 OCSE items evaluated. Items currently under study or already defined in other NASA contracts are identified and were removed from further study in the OCSE contract. The higher ranking items remaining, including those similar in function to each other, are listed in Table 4.3.2-4. These items were selected for further evaluation; additional screening was performed in Part III to identify two or three critical OCSE items.

Table 4.3.2-3 OCSE Preference Order List

RANK	OCSE CANDIDATE	REMARKS
1	Manipulator, mobile base, ≥ 5 DOF	Selected for further study
1	Manipulator, fixed base, ≥ 5 DOF	Selected for further study, same as previous item
2	Docking Device for Joining Vehicles (e.g., large systems)	Selected for further study
2	Manned Cherry Picker Attached to Long Boom (with Manipulator Arms)	Selected for further study
2	Base CHAD Module	Selected for further study
3	Fixed Base Long Boom, ≤ 4 DOF	Selected for further study
3	Manipulator, Dexterous, ≥ 5 DOF	Work effort covered in P-FMA Contract NAS8-31487
3	Manned Cherry Picker Attached to Structure (with Manipulator Arms)	Selected for further study, similar to earlier item
3	Modularized Communications System	Ref JSC-12702, CRT assessment, assigned to communication/control center
4	Commodities Storage Module	Selected for further study
4	Maintenance and Repair Module	Selected for further study
4	Dual Manipulators	Selected for further study, similar to earlier item
4	Fixed Base Extendable Boom	Selected for further study, similar to earlier item
4	Personnel and Material Transporter Structure Attached (suited crew; open structure)	Selected for further study
4	Docking Device with Personnel Transfer	Skylab and Shuttle crew transfer data applicable
4	Free Flying Manned Cherry Picker, Docking Capability (with Manipulator Arms)	No further detail planned, reference ECWS study, NAS9-15290
4	Remote Manned Maintenance Vehicle	Similar type activities in progress at JSC and MSFC
5	Materials Transporter Structure Attached Open	Selected for further study, similar to earlier item
5	EVA Module	Selected for further study
5	Manipulator End Effector, Self-Replaceable	No further detail planned, ref NAS8-30266
5	Fixed Base Module Remove/Replace Mechanism	No further detail planned, IOSS study NAS8-30820
5	Modularized GN&C System	No further detail planned, Space Docking Study, NAS9-31542
5	Central Tracking Station for OCSE	No further detail planned, assign to comm/control center
6	Subsystem Sheet Insulation Remove/Replace Installer	No further detail planned, critical thermal interactions
6	OCSE Storage Panels	Selected for further study
6	Personnel and Material Transporter Structure Attached (suited crew, with cargo bay doors)	No further detail planned, similar to other item
6	Fluid Transfer Commodity Servicer	No further detail planned, assign to OTV storage module
7	Module Replacement Mounting Plates	Covered by ongoing effort, IOSS Study Contract NAS8-30820
7	Personnel and Material Transporter Free Flying (suited crew)	Selected for further study, also reference ECWS study, NAS9-15290
7	Personnel Transporter Structure Attached (suited crew, open and closed)	No further detail planned, ref ECWS Study, NAS9-15290
7	Commodity Servicer by Module Replacement	No further detail planned, ref IOSS Study, NAS8-30820
7	Special EVA Tools for Initial Setup	No further detail planned, ref Skylab and Shuttle EVA tools
8	Laser Alignment System	No further detail planned
8	Portable Heat Source	No further detail planned
8	Assembly Jigs	No further detail planned, dedicated to specific SPS configuration
8	Materials Transporter Free Flying (suited crew, open structure)	Similar type task activities in progress at JSC and MSFC
8	Personnel and Materials Transporter (structure attached, shirtsleeved crew)	Covered by ongoing effort, ECWS study, Contract NAS9-15290
9	Personnel Transporter Free Flying	No further detail planned
9	Video Systems; Lighting, Stereo, CCD, etc	No further detail planned
10	Adhesive Fasteners	No further detail planned
10	Welding Fasteners	No further detail planned
10	Contamination Monitor	No further detail planned
10	Radiator Fluid Leak Monitor	No further detail planned
10	Electrical Power Resupply Vehicle	No further detail planned

Table 4.3.2-3 (Concluded)

RANK	OCSE CANDIDATE	REMARKS
11	Adhesive Fastener (Ultrasonic)	No further detail planned
11	Thermal Insulator (Foam, Paint, Shutters, etc)	No further detail planned
12	Photography Systems	No further detail planned
12	Mechanical Alignment of Joints	No further detail planned
13	Graphic Presentations Aligner	No further detail planned
13	Crew Viewing Windows	No further detail planned
14	Sun Source for Solar Cell Checkout	No further detail planned
14	Infrared Viewing System	No further detail planned
14	TV Reticle for Range	No further detail planned
14	Transit Alignment System	No further detail planned
14	Telescope Viewing System	No further detail planned
15	EVA Joint Adjustment Tools	No further detail planned
15	X-Ray Weld Checker	No further detail planned
15	Ultrasonic Weld Checker	No further detail planned
15	Electrical Continuity Checker	No further detail planned
15	Mechanical Fasteners (Rivets, Screws, etc)	No further detail planned
16	Cable Tension Adjusters	No further detail planned
16	Temperature Indicators	No further detail planned
16	Force and Torque Indicators	No further detail planned
17	Inherent Structure Fastener	No further detail planned
17	Strain Gages	No further detail planned

Table 4.3.2-1 List of Screened OCSE Candidates

• Manipulator, fixed or mobile base, or dual, ≥ 5 DOF • Docking Device for joining large systems • Manned Cherry Picker, attached to boom or structure • Central Hub Assembly/Deployment (CHAD) Module • Fixed-base Boom, long/extendable, ≤ 4 DOF • Maintenance Repair Module • Commodities Storage Module • Personnel/Material Transporter, structure attached • OCSE Storage Panels • Personnel/Material Transporter, free-flying • EVA module

5.0 CONCEPTS EVALUATION/SELECTION

5.1 Part III Objectives

In Part III of the study, the OCSE selected as an output of Part II was identified to a level sufficient to identify the major operational features and programmatic aspects of proposed concepts. Major trade studies required were identified, including factors related to both cost and technology, and the potential application of the OCSE to a SPS Pilot Plant was defined. Finally, the OCSE recommended for further development was identified. Figure 5.1-1 summarizes the approach utilized in Part III and the following paragraphs describe the individual tasks in more detail.

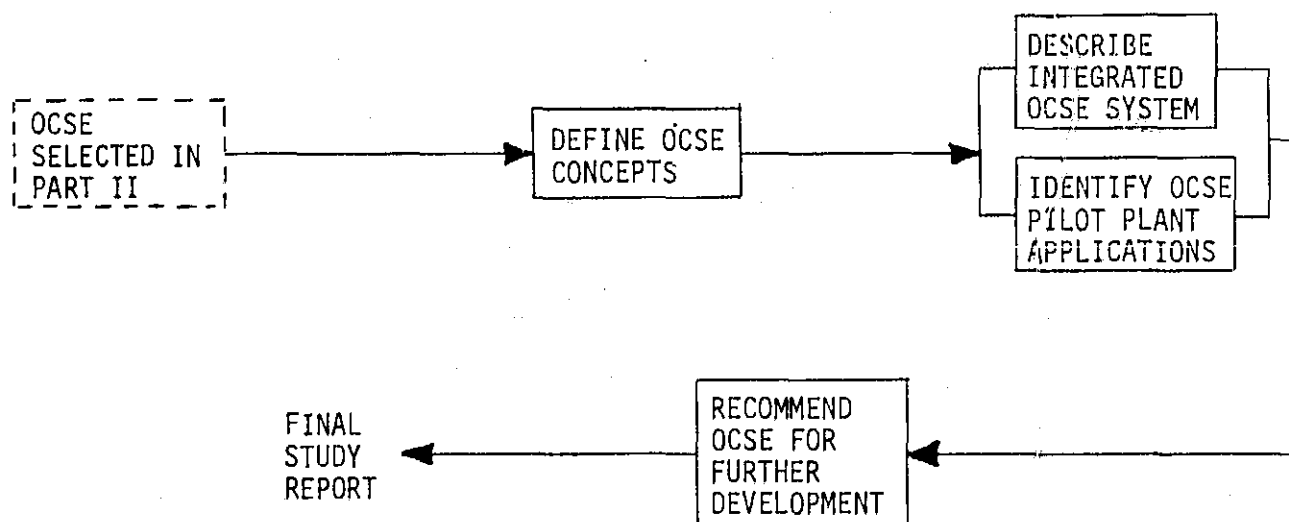


Figure 5.1-1 Part III Functional Flow

5.2 OCSE Definition

The 11 items of OCSE selected in Part II of the study are defined in more detail in the paragraphs that follow. Each item is discussed separately in eight subsections which identify operational and programmatic requirements. Table 5.2-1 lists the subparagraph numbers under which each piece of OCSE is discussed. Table 5.2-2 presents the eight subsections used to define each piece of OCSE in greater detail.

Table 5.2-1 OCSE Description List

PARAGRAPH NO.	OCSE ITEMS FROM PART II
5.2.1	● Manipulator, fixed or mobile base, or dual, ≥ 5 DOF
5.2.2	● Docking Device for joining large systems
5.2.3	● Manned Cherry Picker, attached to boom or structure
5.2.4	● Central Hub Assembly/Deployment (CHAD) Module
5.2.5	● Fixed-base Boom, long/extendable, ≤ 4 DOF
5.2.6	● Maintenance Repair Module
5.2.7	● Commodities Storage Module
5.2.8	● Personnel/Material Transporter, structure attached
5.2.9	● OCSE Storage Panels
5.2.10	● Personnel/Material Transporter, free-flying
5.2.11	● EVA module

Table 5.2-2 OCSE Definition Outline

● Introduction
● Operational Description
● Crew Participation
● Concepts
● Subsystems
● Environmental Factors
● Interface Considerations
● Development Plan

5.2.1 General Purpose Handlers: Manipulators

5.2.1.1 Introduction - Orbital construction and assembly will require the use of manipulators. The manipulator systems will range from simple to complex, manual to automated control, single to multiple degrees of freedom, short to long in length, and gross to fine positioning accuracy. A summary of the wide variation in manipulative activity is presented in Table 5.2.1-1.

Table 5.2.1-1 Manipulator Summary

- Perform Tasks Requiring Multiple Degrees Of Freedom
- General Purpose Mechanism (≥ 5 DOF)
- Manipulator Types Include
 - Fixed Base
 - Mobile Base
- Mounted On Or Interfaces With
 - Dedicated Structure
 - Modules
 - Crew Work Platforms
 - Long Booms
- Masses Handled Range From 5 To 700,000* kg
- Translation Distance: 10m To 900[†]m
- Manipulator Lengths: 3m To 1,000[‡]m

-
- Column Cable Peripheral Cable Reels
 - ‡ Tension Rods On Truss Type SPS
 - MPTS Extension Structure

5.2.1.2 Operational Discussion

5.2.1.2.1 General - As indicated in Table 5.2.1-1, the general purpose manipulator types include fixed base and mobile base. The fixed-base manipulator is defined as an articulated arm with five or more degrees of freedom whose base is fixed-mounted to a platform, structure or facility even though the facility to which it is attached may move.

The mobile types include manipulators that walk on the joints or beams of the structure, those that move on wheels, and fixed tracks (which are

either part of the structure or are an addition to the structure) and those that move on tracks of a pivoting boom. It should be noted that free-flying devices are excluded from this discussion.

The advantages of the mobile manipulator over the fixed-base type is that the former can move from one work area to the next, thus eliminating the need for very long manipulator arms or the need for a multitude of manipulators. Mobile manipulators also provide a logical means of completing work in one area and moving on to do work in the next area (e.g., component installation), as opposed to having the construction tasks "brought" to the fixed manipulator. The disadvantages of the mobile manipulator are obvious; namely, that the structure must have some type of provisions for the mobility and the overall manipulator system will be more complex.

5.2.1.2.2 Applications - The fixed-base manipulator is used as general purpose construction support equipment for the truss-type SPS, the column-cable SPS and the thermal SPS, including the MPTS. Functions the manipulator can perform include stringing and attaching cables, handling arrays, attaching wiring, etc. It can also be used to transport material and crew from one point on the structure to another within its reach envelope. In addition, the fixed-base manipulator would be incorporated as part of other OCSE systems. The spectrum of this type of application is shown in Figure 5.2.1-1.

The mobile manipulator performs essentially the same types of construction tasks as the fixed base. In addition, it can be used to transport material and crew over long distances.

Table 5.2.1-2 summarizes component installation activity as an example of a typical manipulative task application.

5.2.1.3 Crew Participation - Each of the fixed-base manipulators will be controlled by a single operator having a direct view of the work area plus indirect viewing via TV for auxillary views. In the case of a mobile manipulator the control station would also have mobility to enable the control station to "tag along" with the manipulator system.

5.2.1-4 Concepts - Manipulator systems for application in space are beyond the conceptual phase. Recently, a protoflight manipulator arm (PFMA)

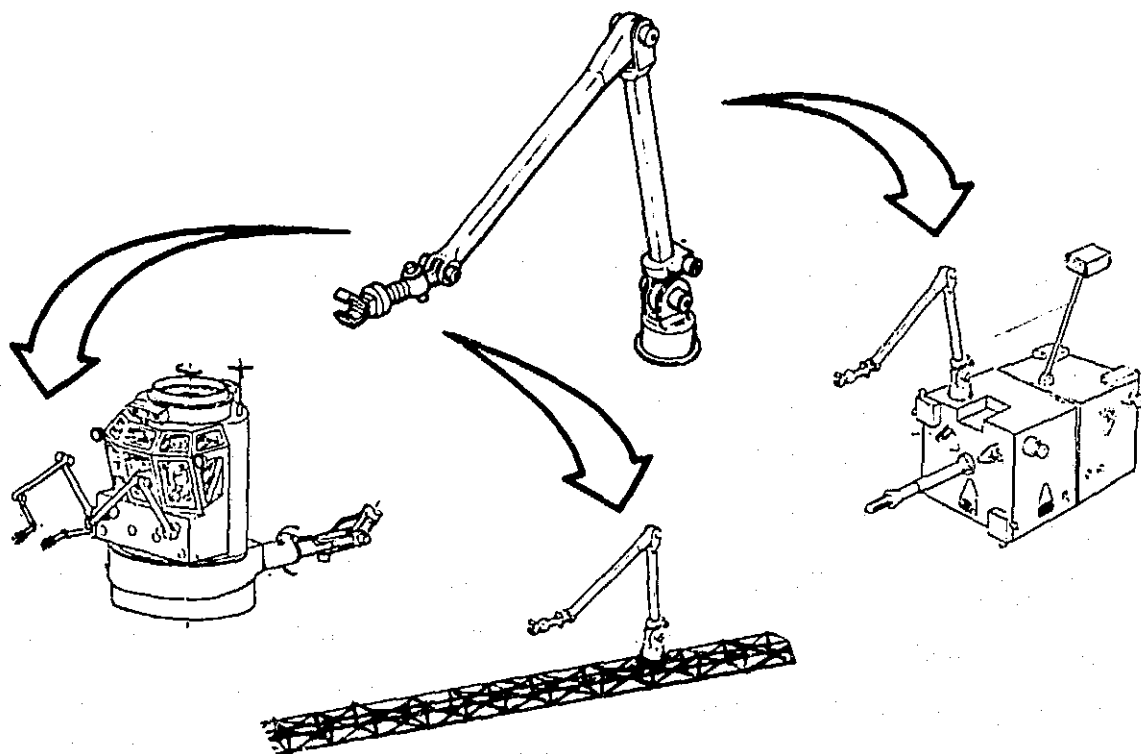


Figure 5.2.1-1 Manipulator Applications

was delivered to NASA-MSFC by Martin Marietta. The PFMA, illustrated in Figure 5.2.1-2, is an eight foot arm designed for application on the Earth Orbital Teleoperator System (EOTS) and is capable of being operated in a space environment. Also, the Shuttle Remote Manipulator System (SRMS) will provide a technology base for medium length manipulator systems.

However, for construction of large space structures, longer manipulators will be required. One such concept, illustrated in Figure 5.2.1-3, is a long manipulator used to provide installation of wiring on the underside of the microwave subarrays.

Table 5.2.1-2 Typical Manipulative Task: Component Installation

Component	Thermal Radiator Panels	Thermal Reflector Facets	MPTS Subarrays
Quantity:	2,944/Cavity	16,500/Reflector	7,854/MPTS
Size:	10m x 20m	30m x 30m	10m x 10m
Attachment:	Four Point	Single Point	Three Point
Secondary Structure:	1.5/5m Beams 10-20m Apart Parallel	1.5m Beams 10m Apart Parallel	<1m Beams ~10m x 10m Parallelograms
Primary Structure:	5/20m 4 Sided	5m Beams 340m Apart "Rectangular"	4.3m Beams ~130m Apart "Parallel"
Pointing Requirements:	None	Mechanically (0 DOF)	Electronically
Proposed Assembly Technique	Long Manipulator	Travelling Crane	Mobile Manipulator
Dimensional Data	Length: ~250m	Base: 340m	Base: 18.5m Length: 22m
Description	Installs One Beam Or Radiator At A Time	Installs 10 Beams Or ~11 Facets Simultaneously	Installs One Beam Or One Subarray At A Time

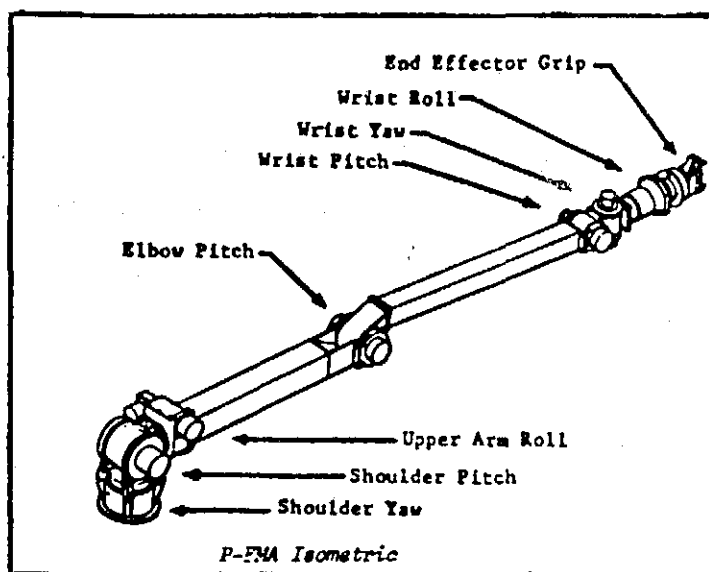


Figure 5.2.1-2 PFMA Isometric

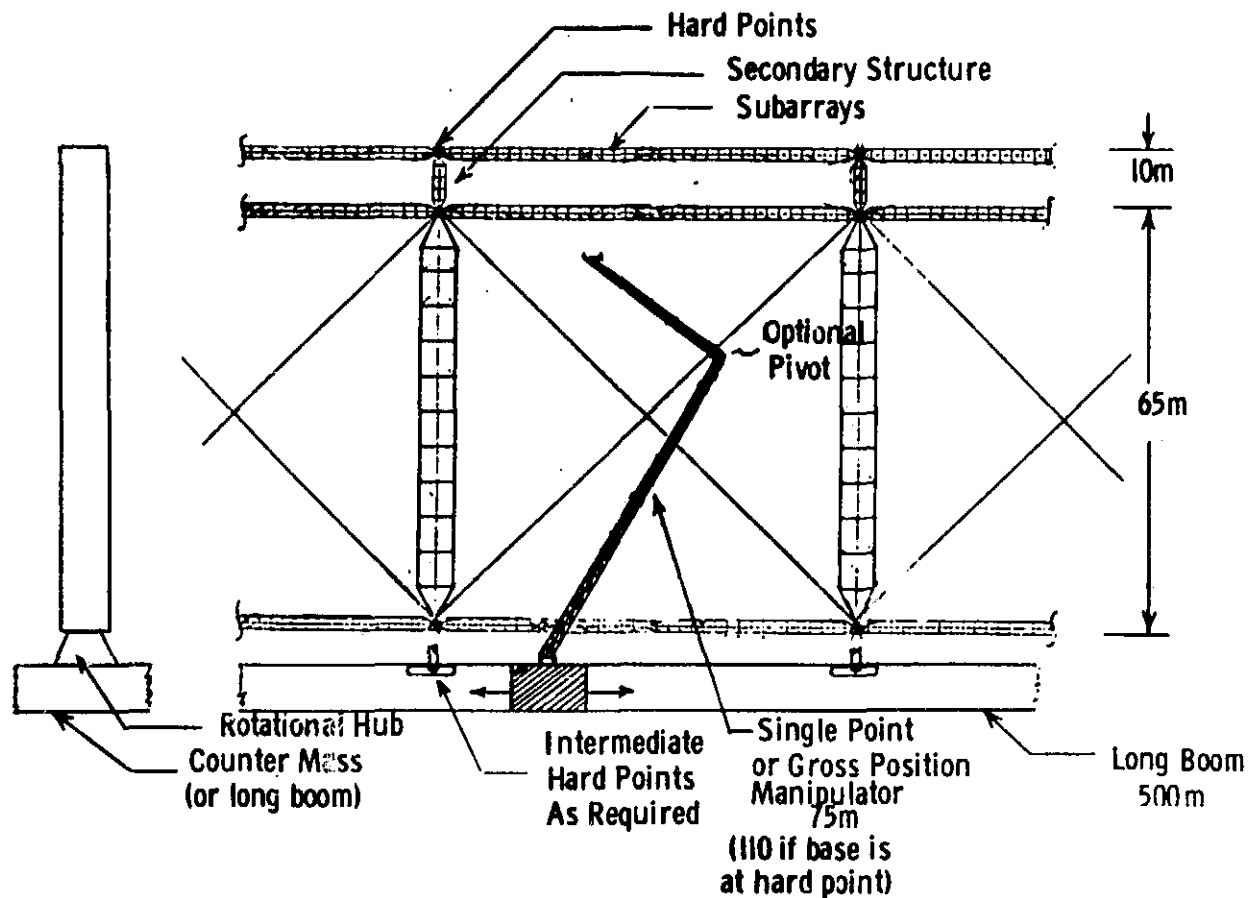


Figure 5.2.1-3 Manipulator for MPTS Underside Access

As indicated earlier, the mobile manipulator system provides one means to reduce manipulative length requirements. A typical concept is shown in Figure 5.2.1-4. This bridge-crane concept might span, for example, two concentric rings of the MPTS. Mobility is provided by two pivot/attachment mechanisms. The carriage walks by releasing one attachment point and pivoting about the other.

The manipulator systems are summarized in Table 5.2.1-3. Note that the overall length requirements range from approximately three meters to over 50 meters.

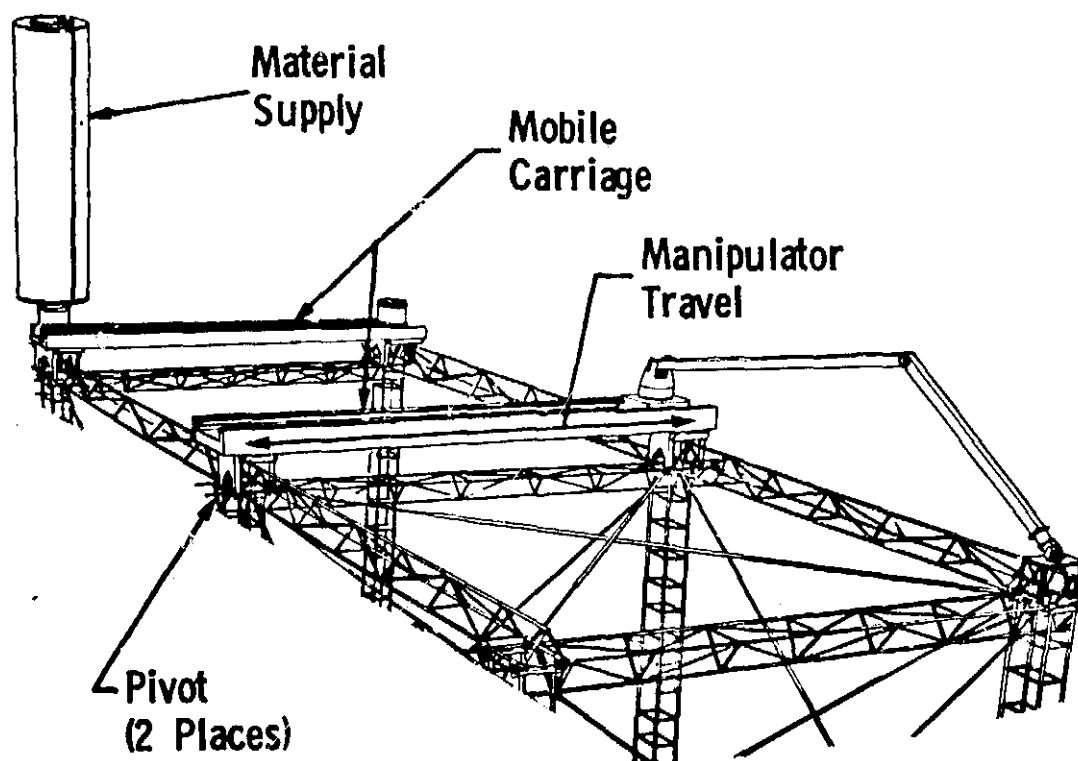


Figure 5.2.1-4 Mobile Manipulator Concept

Table 5.2.1-3 General Purpose Manipulator Systems Summary

	Small	Medium	Large
Length (m)	3 - 10	10 - 50	Over 50
S.O.A.	PFMA	Extended SRMS	SRT Required
General Characteristics	Precise, Dextrous	Precise To Gross Positioning	Gross Placement Of Massive Objects
Typical Mounting Locations	ECWS EOTS	Fixed Base Mobile Base Long Booms	Fixed Base
STS Impacts	None	Assembled On-Orbit	Assembled On-Orbit

5.2.1.5 Environmental Factors - The major environmental factors affecting the manipulator designs are the hard vacuum and thermal impacts encountered over the extensive operational life requirements. Areas of greatest concern are rotating bearings, bearing surfaces, gears and lubricants. These are common problems for all mechanisms exposed to space environments.

5.2.1.6 Interface Considerations

5.2.1.6.1 Launch Vehicle - Methods to fabricate on-orbit or assemble a prefabricated segmented system must be considered in cases where the manipulator length is not compatible.

5.2.1.6.2 SPS Construction Facility - The stiffness of the structure must be compatible with the loads developed by the manipulator system at the mounting interface. Power, data and communication interfaces must be provided. In addition, the manipulator system will interface with the OCSE stowage panels containing the various end-effectors/tools required for the construction task.

5.2.1.7 Trade Studies - The following are areas in which trade studies are required:

- a. Establish size and length based on both application and mobility;
- b. Generate preliminary timeline data to assist in scoping the number of manipulators and the operational rates required;
- c. Determine loads developed on the manipulator and the SPS structure;
- d. Investigate the number of degrees of freedom vs the loads/lengths;
- e. Analyze dual manipulator control techniques.

5.2.1.8 Development Plan - The future activities recommended are shown below in Figure 5.2.1-5. The activity falls into three general areas--supporting research and technology, simulation/demonstration and system fabrication, integration and verification. The SRT activity provides the long-lead support required to define the technologically feasible development paths. The resulting data feeds into the simulation/demonstration testing activity, which provides the means for discriminating between technologies and selecting a preferred development approach. The recommended program applications and integration activity must be defined to assure that all manipulative tasks are considered in perspective. The development and implementation must be responsive to all requirements in a cost effective manner, not piecemeal as the problems arise. Maximum advantage should be taken of the SRMS development so that the lessons learned can be applied to the development of the longer arm.

MILESTONE DESCRIPTIONS	SCHEDULE											
	77	78	79	80	81	82	83	84	85	86	87	88
● SYSTEM DEFINITION/EXPLORATORY TECHNOLOGY												
MANIPULATORS IN SPS CONSTRUCTION	—											
CONTROL STUDY (MANUAL TO AUTONOMOUS)		—										
MAN/MACHINE INTERFACE DEVELOPMENT			—									
◊ COMMIT TO TECHNOLOGY ADVANCEMENT			▽									
● TECHNOLOGY ADVANCEMENT												
- GROUND BASED DEVELOPMENT												
GROUND SIMULATIONS AND TEST				—								
- SPACE EXPERIMENTS												
TASK BOARD OPERATIONS					—							
- SPACE SUBSCALE SYSTEM EVALUATION												
PILOT PLANT 0, SPS							—					
PILOT PLANT I, SPS								—				
◊ COMMIT TO SYSTEM DEVELOPMENT											▽	
● SYSTEM DEVELOPMENT												

Figure 5.2.1-5 Manipulator Development Schedule

5.2.2 Docking Device for Joining Large Systems

5.2.2.1 Introduction - One of the key operational technology areas identified in the early construction scenarios was the activity and hardware associated with rendezvous and docking of free flying space systems. Activities identified included requirements calling for a fleet of manned through automated spacecraft which would provide space transportation for construction personnel and materials. Some of the basic transportation routes that were considered are typified by the following:

- Cargo from the HLLV in LEO (28.5° inclination) to fabrication facilities or construction site in LEO.
- Cargo from the HLLV in LEO (28.5° inclination) to construction sites in GEO.
- Rotation of personnel to different construction facilities.
- Material/components from storage facility to assembly facilities (column cable).
- EVA personnel out to a work site.
- Rendezvous and docking of large assembled structure sections.
- Transport and placement of construction equipment onto the construction facilities or SPS.
- Construction personnel rescue vehicle (EVA, etc.).
- Subsystem replacement modules out to failed construction equipment.
- Supply of SPS elements/construction materials out to the construction equipment.

All of these functional activities require rendezvous and docking. The diverse conditions and vast number of different hardware configurations involved makes this problem very complex with numerous operational options available. These operations may be under direct manned control as in the case of Shuttle or a manned orbital transfer vehicle. Another prime mode would be the remote manned control such as an unmanned free flying teleoperator or cargo transport vehicle. The last and most complex operational mode would be the autonomous rendezvous and docking.

The rendezvous and docking activities for this study were considered to be synonymous with the positioning and joining of SPS subassemblies. For example during construction and assembly of the SPS, several large (mass $> 10^5$ kg, linear dimensions > 500 meters) elements, separately constructed, must be joined together to form a structural unit. Some examples of this type of activity include attaching the MPTS to the main body of the SPS, joining the central hub elements of the column/cable SPS, and joining the separate solar concentrator modules of the thermal engine SPS. The technology required to effect docking of such large systems must be demonstrated so that construction activities can be more firmly established.

5.2.2.2 Functional Discussion - Based on past space programs direct manned rendezvous and docking has been operational since Gemini, but remote manned and autonomous rendezvous and docking was considered a new technology area. This area can be separated even further into small systems and large systems. Small systems are those systems which can be docked or joined by a single mechanism similar in design and size to ones used on past programs, while large systems in general would include those systems having docking characteristics considerably different and more complex than present state-of-the-art.

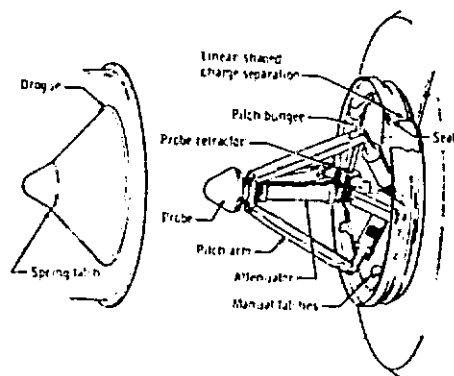
The study emphasis was to investigate docking requirements for future systems to determine the feasibility of developing a universal docking concept. The envisioned hardware to do this could be a single unit design in a family of sizes with the capability to accommodate various sized vehicles onto various configured surfaces. In addition to hardware configuration the question of remote operation -- either with remote manual control, autonomous control, or some best-mix hybrid approach must be addressed. For the device design, the requirements arrived at, dictated a new design which was different from the existing Apollo, Apollo/Soyuz and Shuttle in that they were required to accommodate a pressurized crew transfer tunnel. This requirement did not exist for this proposed OCSE which resulted in a reduced weight and complexity penalty. However, past manned rendezvous technology was relevant in the area of sensors used for docking. A review of docking mechanisms applicable to structurally joining two systems in orbit was conducted. A sample of related source material reviewed follows:

Study Title/Company	Year
Space Tug Automatic Docking Control Study, Lockheed Missiles & Space Company	1974
IUS/Tug Payload Requirements Compatibility, McDonnell Douglas Astronautics	1974
Space Tug Avionics Definition Study, General Dynamics/Convair Division	1975
Integrated Orbital Servicing Study, Martin Marietta Corporation	1975
Multiuse Mission Support Equipment (MMSE), Martin Marietta Corporation	1975
Earth-Orbital Teleoperator System Concepts & Analysis, Martin Marietta Corporation	1976
Space Tug Docking Study, Martin Marietta Corporation	1976

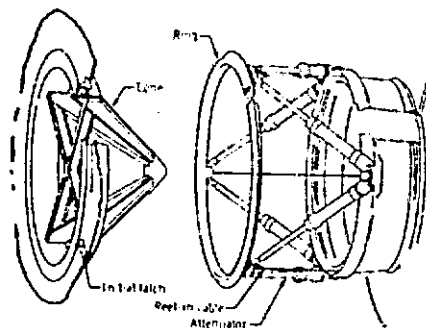
5.2.2.2.1 General - In general the objective of this effort was to match the general docking requirements identified in part I of this study with concepts and results developed in past docking studies. In summary, the development of the preferred docking concept must remain flexible in performance capability while still making maximum utilization of the docking experience generated by the NASA in the decade since Gemini first docked with the Agena target vehicle.

A quick summary of past docking hardware is presented in Figure 5.2.2-1. The first operational docking mechanism used on the Gemini employed a large scale probe/drogue approach. This demonstration system was not driven by the more complex operational objectives that were to beset the Apollo system -- and as a consequence was heavier and more unwieldy than the next generation of docking mechanism design.

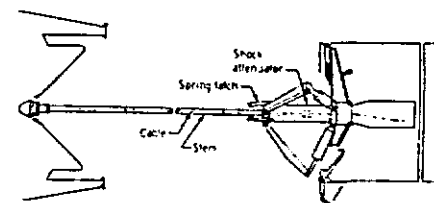
The Apollo development process evaluated a variety of candidate approaches, as illustrated across the top row in Figure 5.2.2-1. The Apollo requirements led to the selection of the small scale probe/drogue, where the probe mechanism was mounted in the crew transfer tunnel. The probe/drogue concept is carried on in this study as one of the prime mechanism candidates.



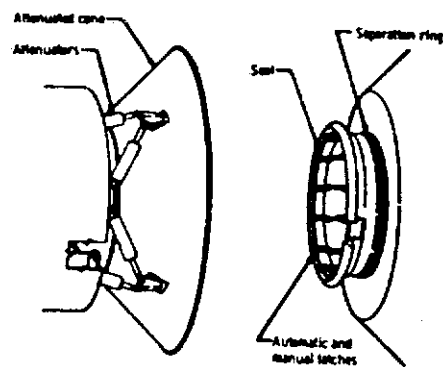
Probe & Drogue



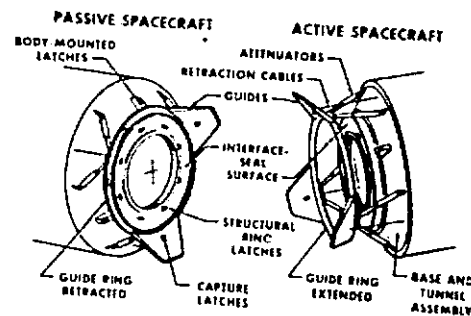
Ring & Cone



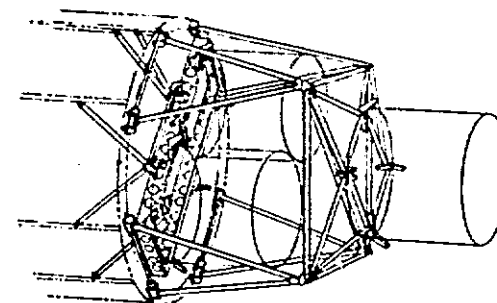
Stem & Cable



Gemini



ASTP



MDAC Square Frame

Figure 5.2.2-1 Existing Docking Concepts

The most recent flight proven docking mechanism is the androgynous Apollo/Soyuz test project device (ASTP). In this case, the mechanisms mounted on both spacecraft are identical. This approach has considerable merit in the docking of two manned vehicles where crew transfer is required.

Recent NASA studies have provided further docking mechanism background data. McDonnell Douglas has been advancing the state of development for a square frame docking mechanism for some time and have presented several concepts similar to one shown on the bottom row of Figure 5.2.2-1.

Much of the information and data presented for this effort has been addressed in previous studies conducted for different NASA centers, particularly in the areas of rendezvous techniques and appropriate sensors. The intent was to build on past experience and previous studies and concentrate on design anomalies resulting from impacts due to size, mass, cooperativeness, final alignment, interfaces, and forces.

5.2.2.2.2 Guidelines and Assumptions - A review of previous rendezvous and docking programs identified areas of consideration which must be factored into any activity to conceptualize new, operational strategies and resulting hardware for meeting functional requirements. Relevant areas identified were established as guidelines and desirable features for the docking of large systems. Those having a major design impact were selected and grouped as follows:

- a) Establish realistic design criteria so that simplicity of design can be achieved; remain flexible on arbitrarily established requirements.
- b) Design a "forgiving" system by minimizing critical dimensions and sensitive components.
- c) Comprised of mechanically mated, remotely operated parts which "self-align" upon actuation.
- d) Simple, reliable, and flexible performance.
- e) Capable of release on command while minimizing release-induced rotations and translations to the satellite, payload or structure.

- f) Configured and implemented to provide a clear field of view to optical/video, r.f., or laser sensors for docking maneuvers.
- g) Design with three points of contact when latched; less than three is not structurally stable or efficient.
- h) Design for structure to absorb impact loads without shock absorbers or load attenuators, if possible.
- i) Design such that all flight loads are transmitted through the central docking mechanism or, if required, transmitted through peripheral latches and outer structure rather than through the docking mechanism.

5.2.2.2.3 Applications - The applications for maneuvering and docking of systems for the SPS program are many. The more common ones include the maneuvering and docking of manned or unmanned spacecraft to a stabilized space structure, manned or unmanned spacecraft to another manned or unmanned spacecraft and a large space structure to another large space structure, i.e. MPTS to the SECS. The less apparent applications include tasks such as maneuvering and joining of beam assemblies, placement of construction equipment at the construction site, attachment to selected sites on the structure for inspection and maintenance sorties, etc.

5.2.2.2.4 Trade Studies - Areas requiring additional detail analysis includes such items as docking studies, docking dynamics, flight mechanics trajectory analysis, crew productivity and man/machine interactions. Basic maneuvering and docking studies should be performed to identify the design(s) to be pursued. These studies should also address the establishment of requirements typical of those shown in Table 5.2.2-1. Present projections indicate no real major problem areas. Other trade studies include terminal docking analyses to aid in determining the docking mechanism requirements for stiffness, damping, braking, forces and torques and control requirements. Analysis is also required to establish crew productivity. Under the baseline that man is available in-orbit to perform in the EVA mode, his potential capabilities and resulting productivity should be determined. For example, man's visual acuity makes him very valuable for visual tasks such as sightings for gross alignment during maneuvering of objects prior to joining.

Table 5.2.2-1 Requirement Sources for Docking of Large Systems

- System Imposed Sources
 - Determine which is to be active element.
 - Accommodate dynamic loads.
 - Compatible with SGLS or TDRS/STDN
 - Provide and assure safety provisions.
 - Compatible with existing environments.
- Interface Sources
 - Free flyer/passive system.
 - Free flyer/active system.
 - Docking mechanism.
 - Mating elements.
 - Single element with prepared surface.
 - Single element with unprepared surface.
 - Payload support (power, thermal handles, etc.).
 - Indexing options.
- Operational Sources
 - Control modes.
 - Remote manual.
 - Autonomous.
 - Hybrid.
 - Functional docking modes.
 - Active to passive.
 - Active to active.
 - Passive to passive.
 - Functional task operations.
 - Cargo transportation.
 - Maintenance and servicing.
 - Material transfer.
 - Functional docking techniques.
 - Impact or non-impact.
 - Central or peripheral.

5.2.2.3 Crew Participation - Based on present projections it was assumed that man's participation fell within two main categories; as a remote operator at a control station and in an EVA capacity. In the first category, a remote manned system was investigated. The options included looking at manual through autonomous control technique requirements. The sophistication and complexity of Remote Manned Systems to provide this capability varies over a considerable range. In general the man-machine interfaces required to interact with this complexity is the control and display center. Matching of

control center hardware to best satisfy human engineering requirements can result in determining man's productivity.

The role of EVA construction personnel was assumed as a maximum to be that of assisting in deployment and positioning of the structural elements prior to joining and the repair or replacement of failed components on the docking mechanisms. In the area of productivity the assignment of such tasks to man or machine would be highly dependent on many different factors. Some of the more obvious include such items as repetitiveness, complexity, speed required to complete a task, multiple functions associated with task, scheduled versus contingency, activity, etc. Analyses made in these other studies established that the rendezvous and docking system should be designed for remote manual control with the actual docking hardware being compatible for EVA assist in positioning and servicing.

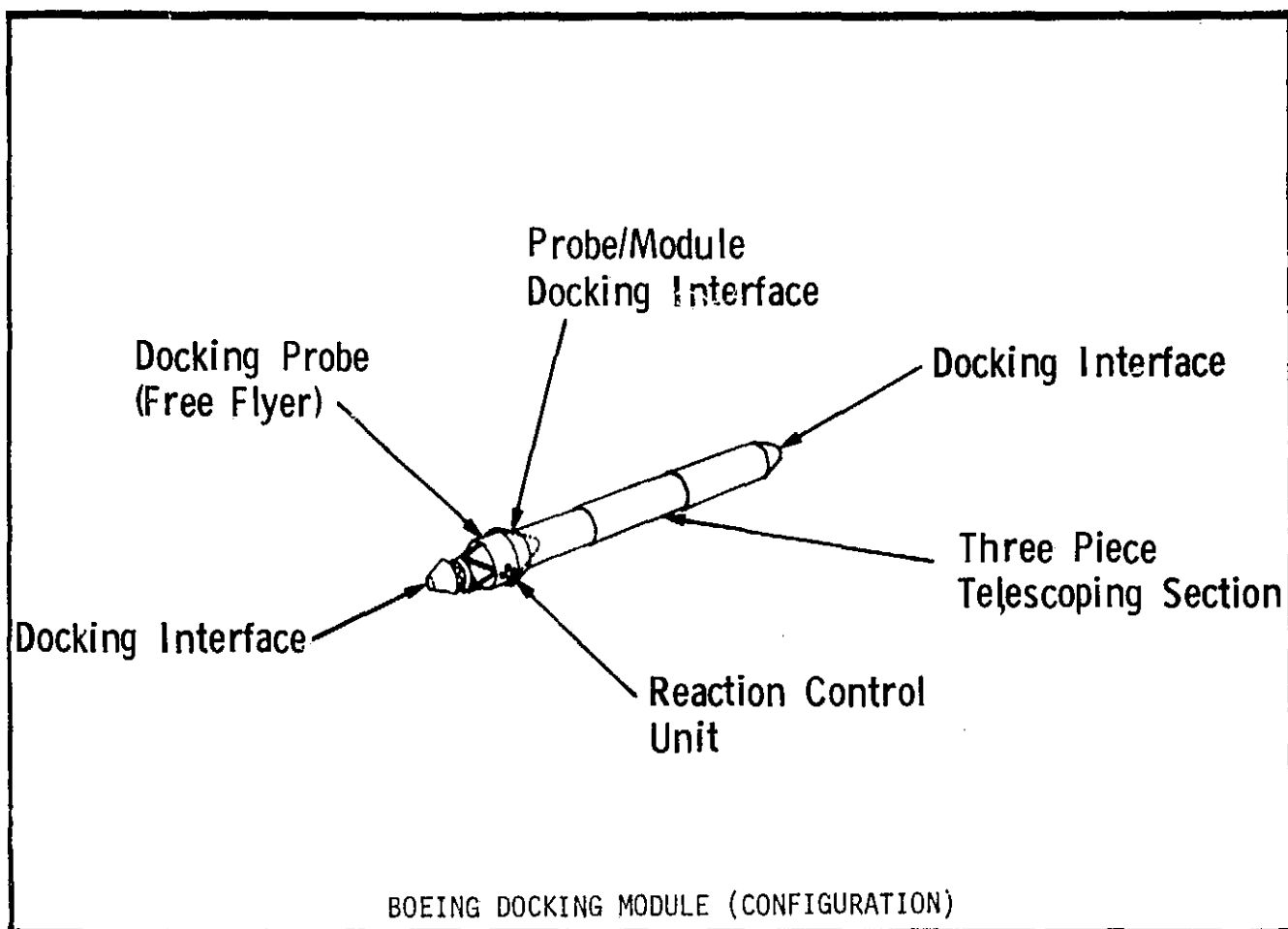
5.2.2.4 Concepts - The primary objective of all docking concept is the eventual structural joining of two vehicles in orbit. To accomplish this, it was recognized that the mechanism used to join vehicles should be designed such that alignment requirements between the two vehicles are not unduly restrictive. These conditions can be different in either displacements (lateral and angular) between the two mating halves of the mechanism at contact or variations in the relative velocity between the two masses.

In spite of these unknown docking characteristics, docking techniques were generated which emphasized only the docking hardware since it was also assumed that any of the sensors used could be adapted to any of the docking concepts.

The concepts generated here were bound by the intent to utilize to a large extent experience gained from past programs.

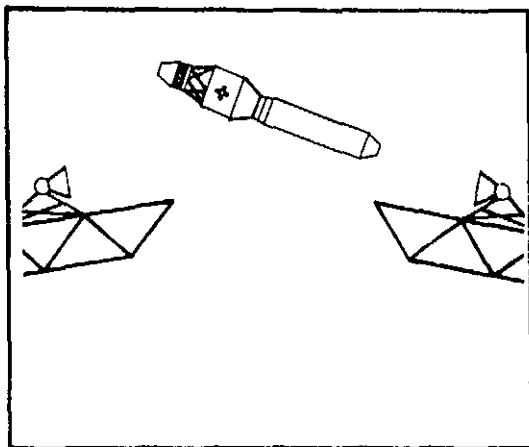
The following paragraphs describe five distinct concepts for accomplishing docking of large systems. The first technique considered has been proposed by Boeing.

It makes use of a docking module with the characteristics shown in Figure 5.2.2-2. This docking module docks with one of the two structures to be joined, then sends out a docking probe (small free flying vehicle attached to docking module by a cable) to dock with the other structure. Meanwhile

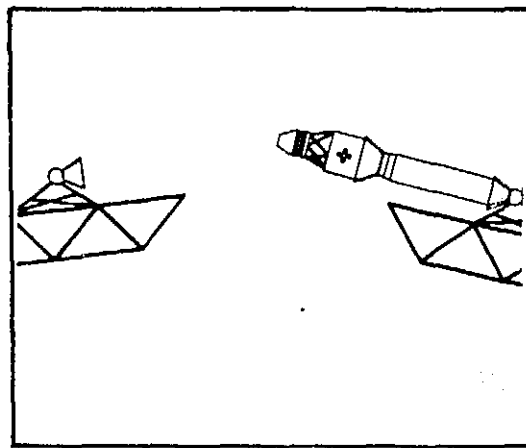


- STEP #1: Module Flown into vicinity of structures to be attached.
- STEP #2: Module docks with interface on one of the structures.
- STEP #3: Docking probe separates from module, dragging cable.
- STEP #4: Docking probe docks with interface on second structure. Telescoping section expands and module reels-in cable.
- STEP #5: Docking probe redocks with module. Structures are aligned.
- STEP #6: Telescoping section contracts to bring structures together. Module holds structures until they are attached.

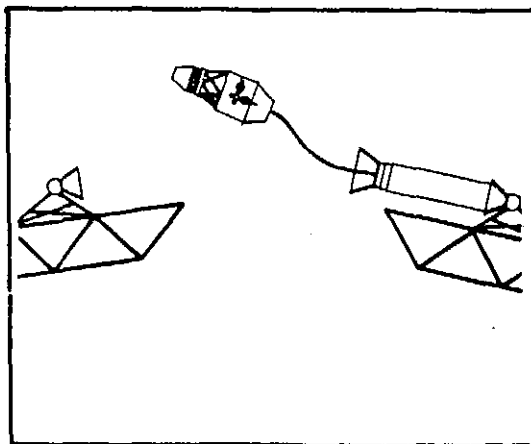
Figure 5.2.2-3 Free Flying Docking Module With Cable



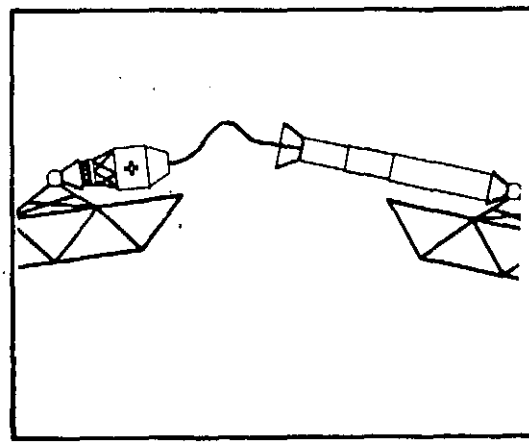
Step 1



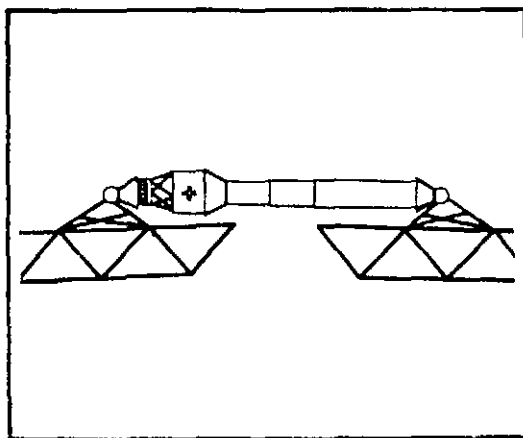
Step 2



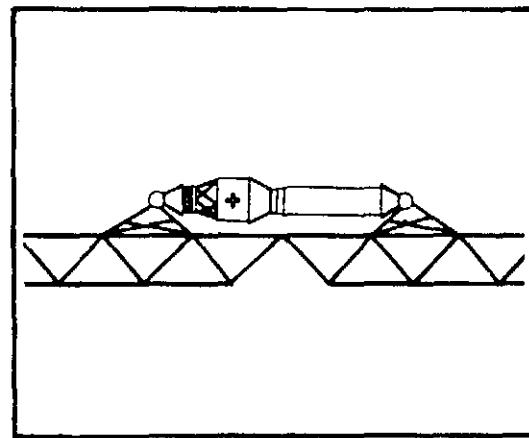
Step 3



Step 4



Step 5



Step 6

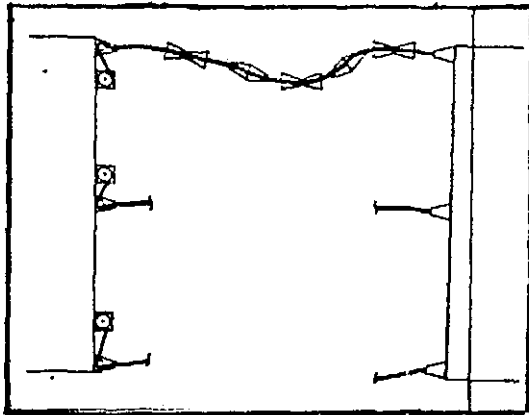
Figure 5.2.2-2 (Continued)

the docking module makes use of its telescoping shell to increase its length. After the docking probe has effected docking the two structures are brought within close proximity to each other by reeling in the cable connecting the docking probe to the docking module. Both structures are kept from rotating by reaction control systems attached to them. After the docking probe has redocked with the docking module the situation looks like that of Step 6, with one structure on either end of the docking module. The docking module and reaction control systems align the structures and then the structures are brought into contact by the docking module (by shortening its length with its telescopic shell). The two structures can then be attached to form one structure.

A second method of docking two large structures which also makes use of cables to bring the structures together is shown in Figure 5.2.2-3. Cables are strung from one structure to the other (using a free flyer). On the cables are self-aligning guides (cones) which, when in contact with one another, form a structural beam of designed length. Step 3 shows how, as the cables are reeled in, the self-aligning guides form beams which hold the structures a predetermined length apart for attachment.

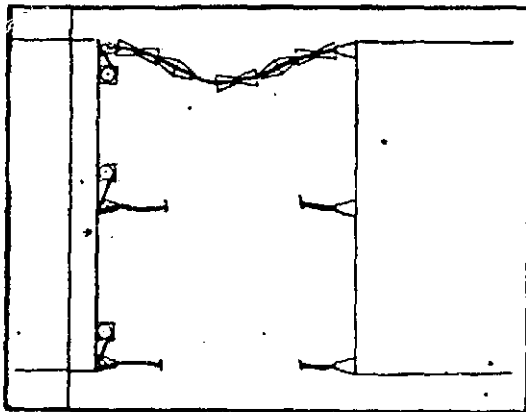
If the large structures are placed in the neighborhood of 50 meters from each other, they can be docked using long booms as shown in Figure 5.2.2-4. The booms, attached to one structure through pivoting joints, are manipulated so that machines on the other structure can grasp the ends of the booms and use them as shown in Step 2 to bring the structures close enough so that they be hard attached. One problem with this method is that the booms (after docking is complete) are no longer used at the site and must be moved if needed for another docking. One way this could be solved is to use the boom as part of the structural attachment. Figure 5.2.2-5 shows how this could be done. Each boom consists of three equal length beams held together with joints and kept straight by break-away joint restrainers. This system uses cable handling cars as shown to build and connect the structural attachments as the two structures are brought together.

Still another method of docking is the use of free flyers equipped with manipulators. A method of this type (proposed by Westinghouse) is shown in Figure 5.2.2-6.



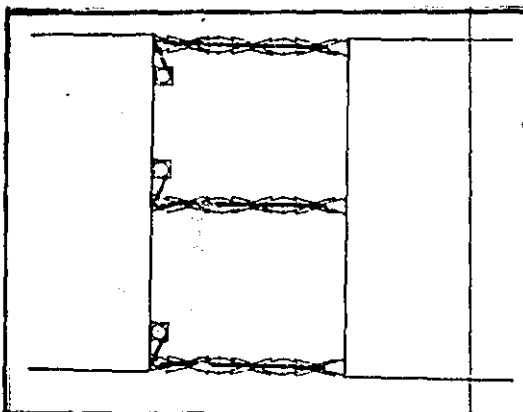
STEP #1

Cables are strung between the two structures to be attached. A predetermined number of self-aligning guides (A), determined by the spacing desired, is placed on each cable. Cables run to motorized cable reels (B).



STEP #2

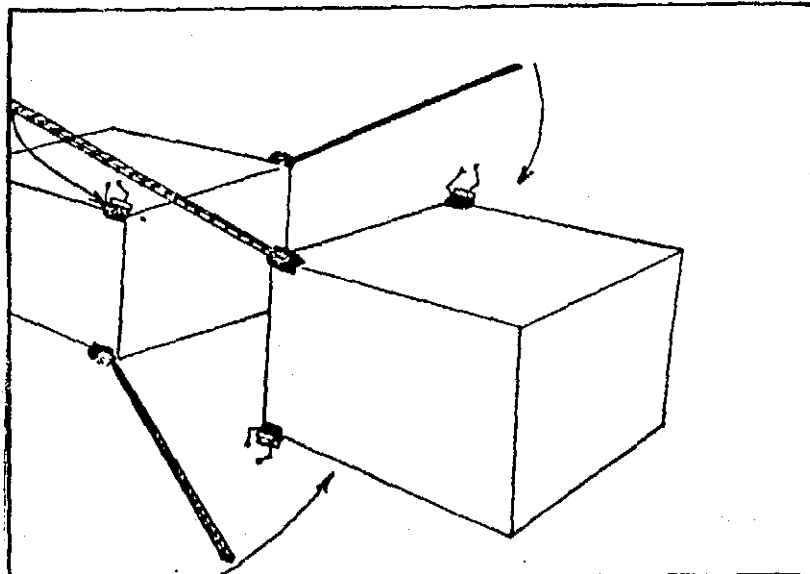
As cable reels take in cable, the self-aligning guides start forming segments of the final spacing beams.



STEP #3

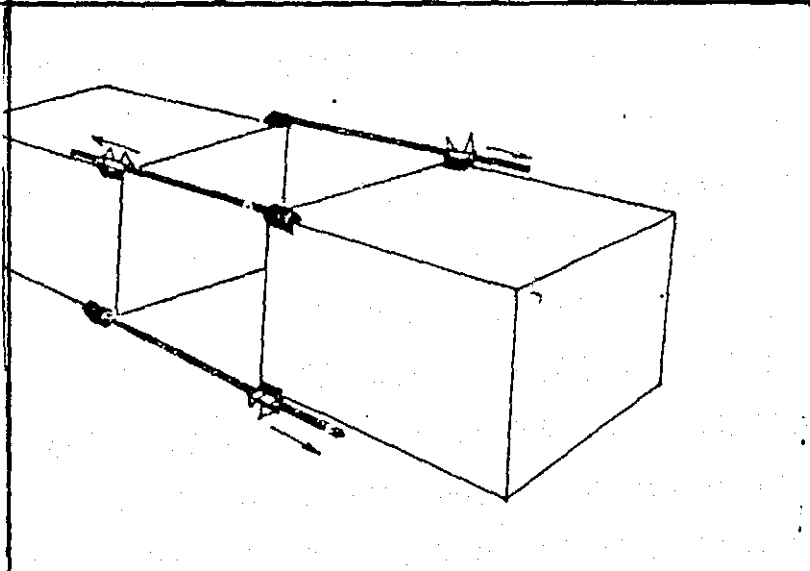
When cables are sufficiently shortened the self-aligning guides form spacing beams which hold the structures the desired distance apart until they are attached.

Figure 5.2.2-3 Docking With Attached Cable System



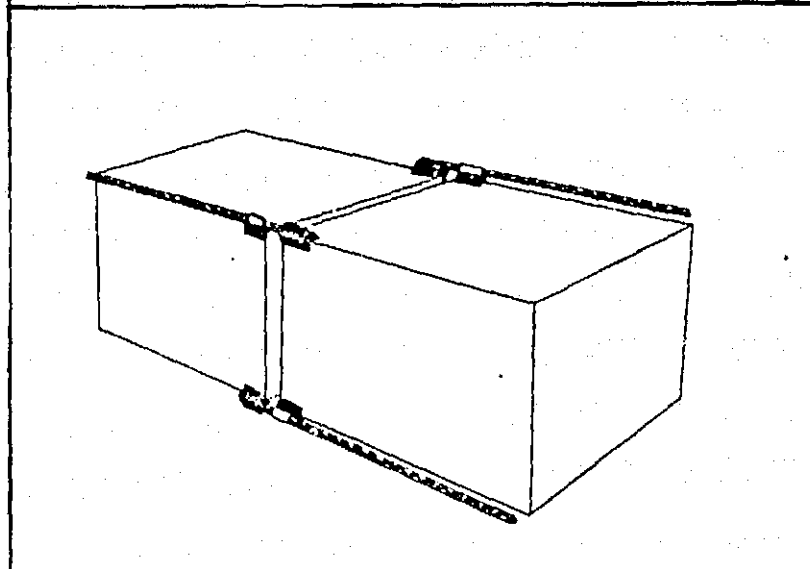
STEP #1

Large structures to be docked are within close proximity of each other. Booms are manipulated to span from one structure to the second.



STEP #2

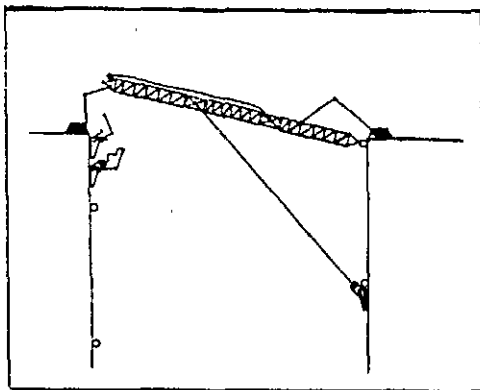
Machines ride along booms to bring structures closer.



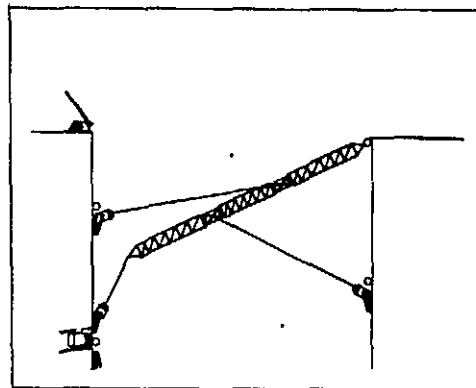
STEP #3

Booms hold structures a pre-determined distance apart until they are attached.

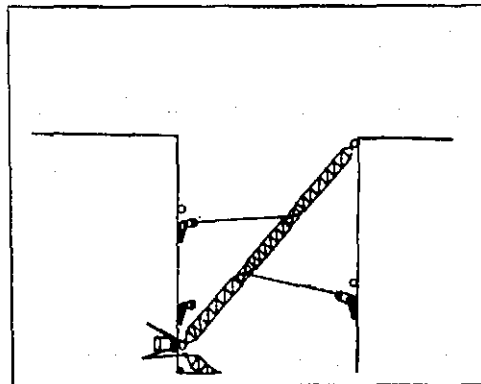
Figure 5.2.2-4 Long Boom Docking Concept



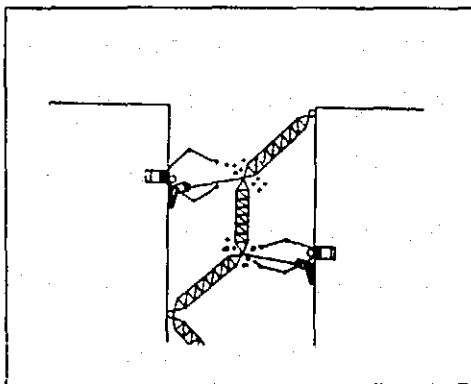
Step 1: Booms Span Structure



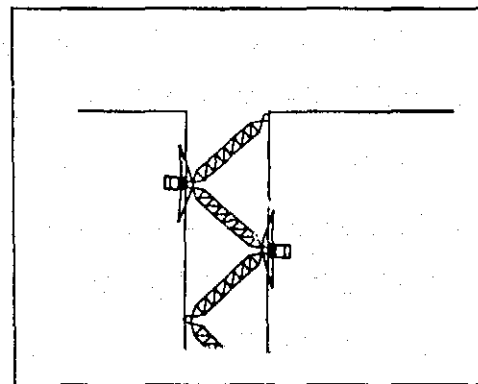
Step 2: Cables Pull Structure Together



Step 3: Boom Attached

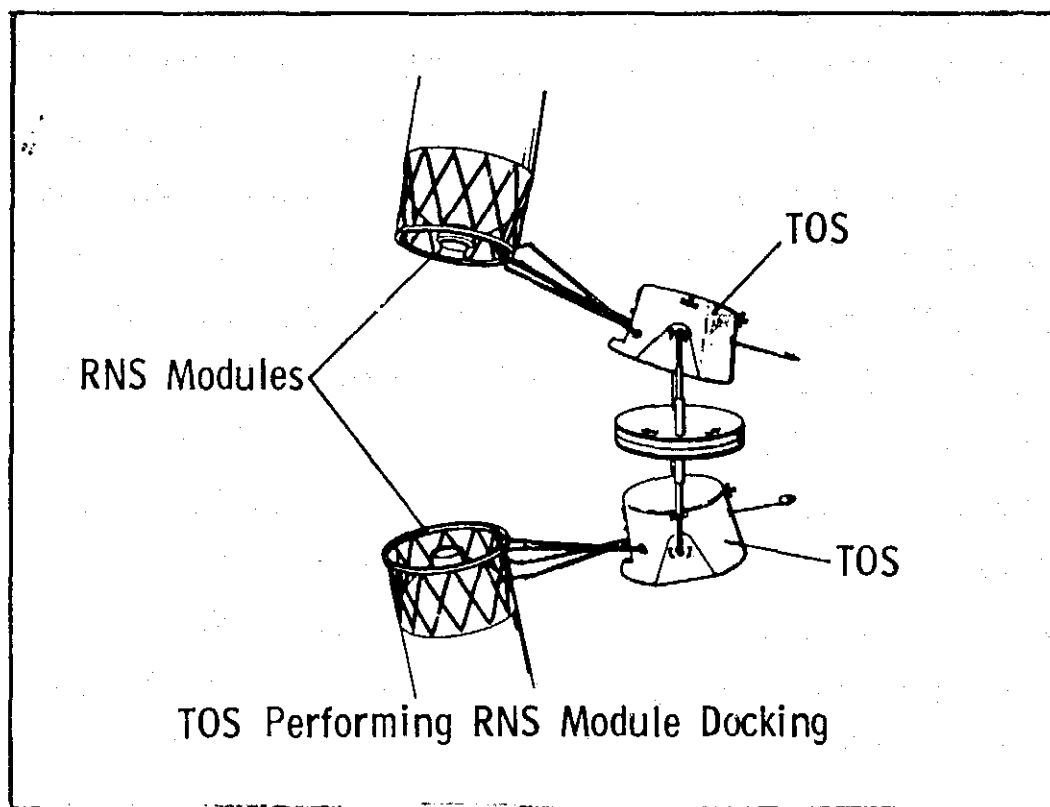
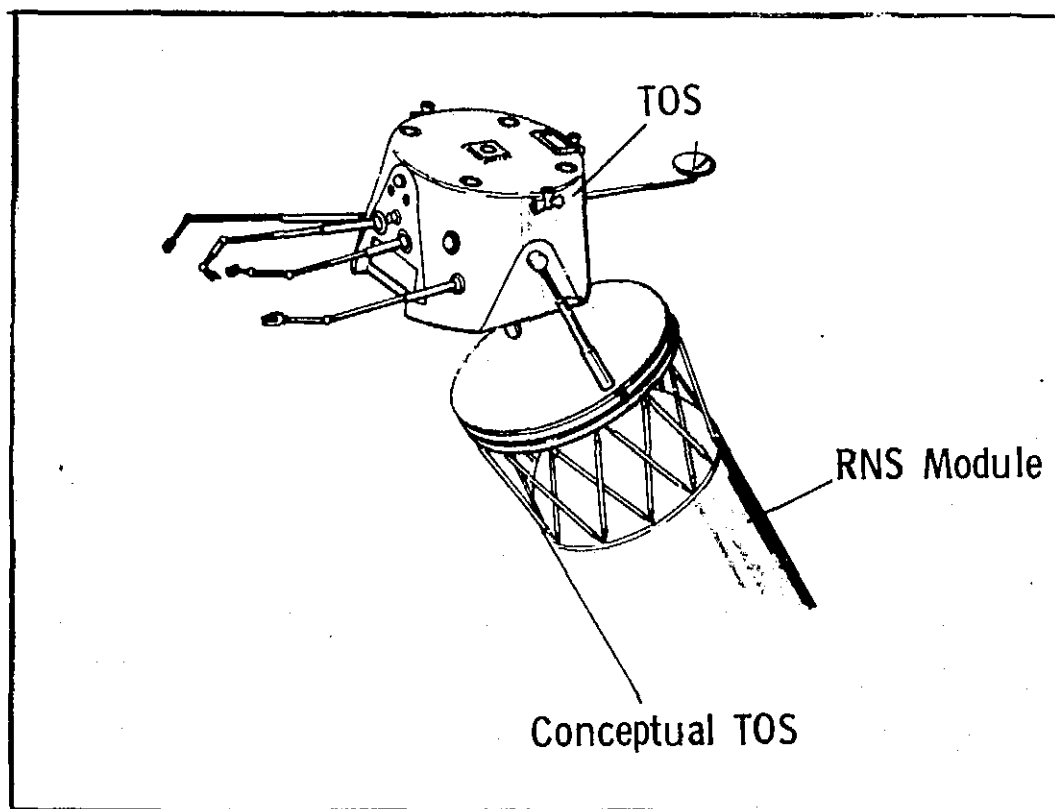


Step 4: Joint Restrainers Broken



Step 5: Cables Pull Other Joints Into Position

Figure 5.2.2-5 Long Booms as Part of Structure Concept



Westinghouse Large Structures Docking Concept

Figure 5.2.2-6 Maneuvering and Docking Using Free Flying Teleoperator Concept

5.2.2.5 Candidate Subsystems - This section shows a number of available or potentially available sensor and mechanism candidates which were compiled from related studies. Data were also collected which related to performance capabilities, physical properties, and costs. Using these candidates as the subsystem basis, system configuration projections were generated which represented combinations of manual through autonomous control for some of the concepts presented in paragraph 5.1.4. The sensors group which seem to have the most future application are listed in Table 5.2.2-2.

Table 5.2.2-2 *Sensor Hardware Candidates*

Subsystem	Candidate	Remarks
Laser Radars TV RF Radars	• Ga As	• Is in development stage, maximum range of 46 km (25 n mi), and requires corner cube retroreflectors.
	• CO₂ Cooperative	• Provides Long Range Capability, Requires SRT
	• CO₂ Non-Cooperative	• Provides capability for skin track ranging at long ranges, requires SRT.
	• Silicon Vidicon	• Being developed for Shuttle.
	• Modified Apollo Rendezvous - Non-Cooperative	• Flight Proven, Minimum S/C Impact
	• Modified Apollo Rendezvous - Cooperative	• Lower Weight and Power
	• Dual Mode - Non-Cooperative (Rendezvous Radar Above Plus Short Range Pulse System)	• Single Unit, Full Range Capability, Minimized S/C Impact
	• Dual Mode - Cooperative	• Lower Power and Weight Than Above

A broad overview of the docking mechanism types and the impacts due to operational criteria are shown in Table 5.2.2-3.

The approach used in combining subsystems into a conceptual system was very simple in that it made maximum use of past experience and studies.

The specific docking mechanism which looked to have good potential was a central soft dock concept which has the advantage of reducing or eliminating contact shock loads and lightening the structure required at the docking or attach points. This is a relatively new concept and would require a thorough analysis.

Table 5.2.2-3 Docking Mechanism Hardware Candidates

Mechanism	System Complexity	Spacecraft Impact	Servicing Compatib.	Spinning Compatib.	Weight
Square Frame	Requires relatively complex structural support mechanisms integral with docking mechanism.	Peripheral docking mechanism has potential for docking/structural support compatibility.	Somewhat limits spacecraft accessible region.	Can be designed into concept.	253 kg (556 lb)
Probe Drogue	Uses developed docking mechanism, requires new design only for static structure.	Central probe & peripheral structural support for delivery/retrieval must be separate.	Provides good access to spacecraft for servicing.	Requires some development of Apollo Probe/Drogue.	441 kg (970 lb) (Standard) 323 kg (710 lb) (Tailored)
Soft Dock	Simple structural support mechanism, but complex soft-dock mechanism.	Eliminates docking shock loads without interfering with deliver/retrieval structural support.	Can use servicing mechanism as soft-dock steerable probe.	Can be designed into concept.	241 kg (531 lb)
Hybrid	Complexity of controlling multiple units.	Combination of above.	N/A	Can be designed into concept.	900 kg (1984 lb)

The primary subsystem concepts considered in more detail included the extendable booms, capture/latch devices and steering mechanisms. Information on these candidates is presented in the following paragraphs.

a. Candidate Extendable Boom Concepts - A variety of extendable boom concepts is illustrated in Figure 5.2.2-7. Extendable tubular booms are elements made of thin metal strips which are wound flat on a spool when stowed and form a circular tube with overlapped or interlocked edges when extended. Two of the most prominent manufacturers of this type extendable boom are Astro Research Corporation of Santa Barbara, California, and Fairchild Industries of Germantown, Maryland. These units have been widely used in space for such applications as antennae and deployment of experiment packages, sensors and cameras.

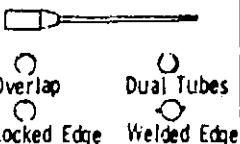
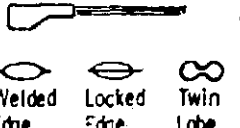
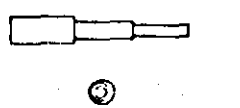
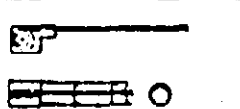
Description	Illustration	Advantages	Disadvantages
Extendible Tubular Booms	 Overlap Dual Tubes Locked Edge Welded Edge	• Fully Developed And Tested • Flight Experience • Light Weight • Stowed Length Acceptable	• Weak In Torsion And Buckling • Tip Deflection Limited • Single Deployment Speed • Axial Load Capability Not Predictable
Extendible Contoured Booms	 Welded Edge Locked Edge Twin Lobe	• Good Bending & Torsional Strength • Reliable For Light Column Loads • Positive Control Of Deployment • Flight Experience	• Buckles In Transition Region • Heavier Than Tubular Booms • Deployment Cycles Limited • Stowed Length Exceeds 1 Ft.
Telescoping Cylinder Booms		• Simple Parts, Structural Shapes • Reliable Deployment • Large Column Load Capability • Conventional Proven Design	• Susceptible To Buckling • Binding Possible When Loaded • Considerable Overlap Required • Stowage Length Unacceptable
Expandable Linkage Booms		• High Expansion Rates • Can Carry Service Lines • Good Stiffness and Bending Strength • Light Weight	• Large Number Of Parts • Compressible Axial Load Limited • Stowage Length Exceeds 1 Ft. • Requires Extension For Probe
Prestressed Element Booms		• Strong In Bending, Shear, Torsion • Very Simple, Reliable Design • Light Weight • Not Degraded By Use	• More Development Work Needed • No Flight Experience • Relatively Large No. Of Parts • Guides Req'd For Torsional Strength

Figure 5.2.2-7 Extendable Boom Concepts

Extendable contoured booms are also made of metal strips which are spool-stowed, generally have larger package envelopes and offer greater structural strength. They have lenticular (quasi-biconvex) or twin lobe shapes with welded, interlocked or overlapped edges. The Viking Surface Sampler boom, made by Celesco, is a welded lenticular shaped boom. Astro Research Corporation and Boeing Company have also made this type boom while the interlocked edge type is made by Sanders Associates, Inc. of Nashua, New Hampshire and the twin lobe type by Fairchild. These booms have been used where heavier tip loads are anticipated. The twin-lobe boom, for example, was used on Skylab to transfer film cassettes between the ATM and the airlock.

Telescoping cylindrical booms have not been used extensively in space but were considered for this application due to their simplicity. Commercial units are built by Sanders and Tri-Ex Tower Corporation of Visalia, California. They consist of a series of close-fitting concentric metal cylinders which telescope for stowage and are extended by screw jack or cable with sufficient overlap remaining between sections to maintain structural strength. Package size for the tubes and deployment mechanisms is a major problem for the soft docking extendable boom application.

Expandable linkage booms consist of lazy tong linkages connected to frames at the linkage pivot points. Extension and retraction are accomplished by moving the first frame relative to the base while working against a tensioned centrally-located cable. A version of this boom, developed by the Martin Marietta Corporation, was successfully flown on Skylab to deploy the optical head of the T-027 experiment.

Prestressed element booms consist of cylindrical segments with centrally located axial holes through which a tensioned cable is run. Cable tension is maintained by springs which permit the segments to be stowed on a spool. As the segments are extended, they form a rigid tubular structure by being compressed by the tensioned cable. A working model of this boom has been built at Martin Marietta Corporation. The General Electric Company and the Illinois Institute of Technology have also prepared working models

using this concept. Its simplicity and superior load capability make it attractive for soft docking application. Additional development work appears to be warranted,

b. Capture Latch Concepts - The three types of capture latch mechanisms shown in Figure 5.2.2-8 have distinct operational characteristics which influence their use. The pivoting probe latch allows angular motion between the the two spacecraft to take place without restraint since the probe is permitted to pivot within the latch fingers. This feature eliminates end moments on the extendable boom but may increase axial loading if axial play cannot be removed. This capture latch concept is much simpler than the clamping type, however, and could more easily incorporate a free rotating probe for capture of spin-stabilized spacecraft.

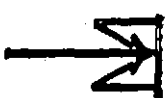
Description	Illustration	Advantages	Disadvantages
Pivoting Probe Latch		• Simple Design • Adaptable For Spin Stabilized S/C • No End Moment On Boom	• Release Difficult • Impact Due To Probe Movement • Centered By Latch Fingers
Clamped Probe Latch		• Controls Attitude Of S/C • Eliminates Longitudinal Impact • Sensor Activated Snubbed Probe Clamp	• Larger Boom Bore Torques • Stiffer Boom Required • Release Difficult
Latch In Probe		• Releasable From Tug • Self Centering • Simplifies S/C Design	• Larger Diameter Drogue Required • Adds Tip Moment To Boom • Extends Storage Envelope

Figure 5.2.2-8 Capture Latch Concepts

The clamped probe type capture latch offers maximum control of the spacecraft and eliminates end play between probe and latch. While a somewhat more complex mechanism than the pivoting type latch, operational features are superior. When a sensor has determined that the probe on the end

of the steered boom has been captured by the drogue, a spring-actuated clamp is released which engages the conical end of the probe and forces it against the inner surface of the drogue, continuing the probe and hinging the longitudinal axis of the boom perpendicular to the X-Y plane of the spacecraft. Engagement speed of the clamp is controlled by an integral damping device. Release of the clamp is accomplished by activating a solenoid which retracts and latches the clamp.

The probe may be a passive, rotating or fixed cone or may have an active latching capability. The concept for a latch type probe shown in Figure 5.2.2-8 employs spring-loaded pivoted fingers which will swing inward under light load to permit the probe to enter a hole in the drogue and expand when the probe is inside the hole to effect capture. This type latching probe places control of latching and release on one side of the interface which minimizes spacecraft impact.

While three separate concepts have been shown, features of each may be combined. We have recommended a clamping type latch with the latch in the probe as the most versatile system.

c. Steering Mechanism Concepts - Steering mechanism concepts considered for extendable boom pointing were of two general types (Figure 5.2.2-9) -- those having bearing-supported pivot points with integral motor/tachometer assemblies in the pivots, and those having flexure pivot points with separate motor drives.

The ATM star tracker gimbal system is the integral type. This developed hardware has very high performance characteristics such as pointing accuracy of 1 arc sec., weight capability of 500 kg, and a gimbal range of ± 90 degrees in one direction and ± 50 degrees in the other direction. This capability is greater than that required for extendable boom pointing for a non-impact docking system. Even if simplified to the greatest extent possible, this system would be more costly than a flexure gimbal system due to the use of many more special parts, and more complex electronic controls. Also, this system would require redesign to meet envelope requirements and to interface properly with the extendable boom housing and spacecraft structure.

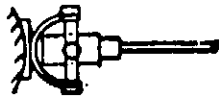
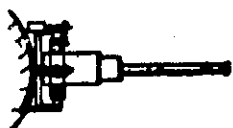
Description	Illustration	Advantages	Disadvantages
Gimbal Steering Mechanism		• Flight Experience • Torquers in Pivots • Integral Position Encoders	• More Complex And Costly • Larger Envelope And Weight • Req'd Size Not Available
Flexure Steering Mechanism		• Simple Conventional Design • Limits Maximum Boom Moment • Minimum Weight, Size, Complexity	• More Development Required • Limited Articulation Angle • More Power Req'd For Drive

Figure 5.2.2-9 Steering Mechanism Concepts

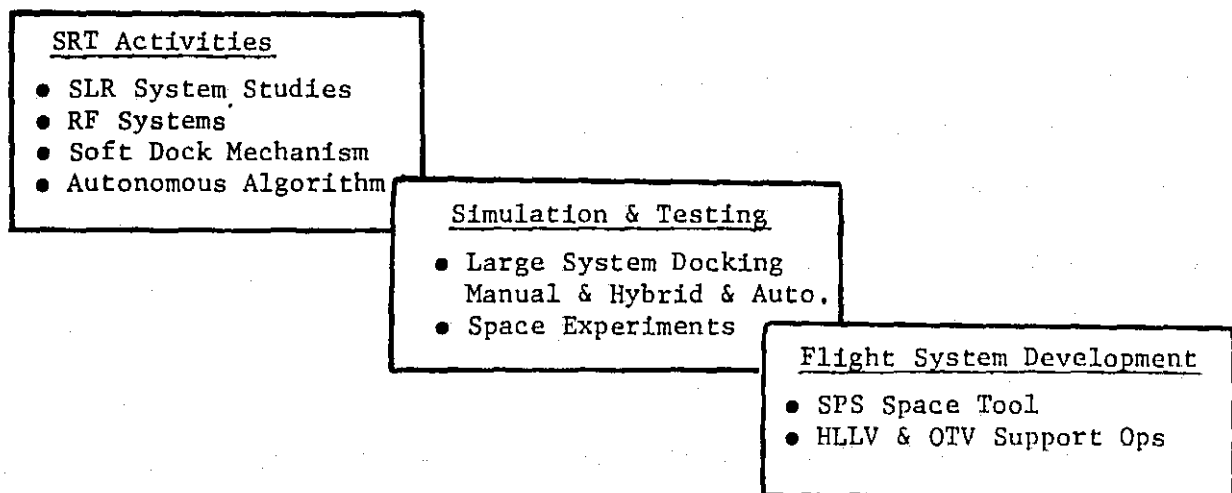
A system using flexural pivots to provide gimbal capability which uses a minimum number of simple parts has been designed by the Martin Marietta Corporation. Type 800 flexural pivots developed by Bendix provides the required deflection angle and radial load capability along with selectable torsional spring rates. Gear motor/encoder units in the size and capability required for boom pointing have been developed and qualified for other space programs and should therefore, be available at reasonable cost. The use of tandem-mounted sets of pivots at each pivot location allows the boom to be steerable while permitting controlled boom movement due to side loads on the boom tip. This is a unique feature of the flexural pivot type of boom steering system.

5.2.2.6 Environmental Factors - The major environmental factors affecting the docking mechanism designs are the hard vacuum and thermal impacts encountered over the extensive operational life requirements. The areas imposing the greatest concern are the rotating bearings and bearing surfaces,

gears, lubricants, material outgassing, vacuum welding, etc. Considerable future effort is required in material compatibility for application in long life components. This is a common problem for all mechanisms exposed to space environments and must be resolved for Shuttle and SPS programs at the program level.

5.2.2.7 Interface Considerations - In general, the interfaces identified with this unit would be similar to those required on past programs. Typical samples of such interfaces are the support structures required to mount the mating halves onto the respective space systems.

5.2.2.8 Development Plan - The future activities recommended are based on the results reached in this study and are summarized in the flow schematic shown below. Activities identified fall into three general areas -- supporting research and technology (SRT), simulation/demonstration testing and flight system development.



The SRT area was considered the most important for planning purposes at this time. This was separated into two categories; maneuvering and docking strategies and associated subsystems. The thrust of the SRT was placed upon the components and performance capability associated with the subsystems. The subsystems of interest were further separated into two lower categories; sensors and mechanisms. Included with the sensors were the electronics for signal conditioning and processing to present a standard interface between other desired control centers. This approach allows evaluation on a common basis with different docking mechanisms and the flexibility for using these sensor systems for other alignment applications.

In the sensor area, only the TV camera has been used in space. However, a new version of the silicon vidicon camera selected for the Shuttle program is recommended for the rendezvous and docking system from the commonality and shared development cost aspects. The scanning laser radar and RF units are new technology or new applications of existing technology.

For the autonomous candidate the SLR and/or RF radar components present new technology that should be pursued before entering a simulation/demonstration program. Although RF radar is an existing and well-known technology, this application represents a new range of operations not fully proven. In conjunction with these new developments the target-mounted reflectors or aids represent areas in which research should be performed. Since user acceptance of the system is enhanced by minimizing the impact on system design, this is a fertile area.

In the mechanisms area, the requirements of the study dictated new designs. The mechanisms applicable to the manual, autonomous, and hybrid systems were much the same. The requirement not to accommodate a shirt-sleeved crew transfer through the docking interface reduced the weight and complexity of such a mechanism. Two basic designs should result -- one for the small vehicle docking (single point) and one for the large system requiring more than one point of attachment. Both designs represent new technology and require additional development before proceeding into ground simulations.

The schedule of activities as shown in Figure 5.2,2-10 provides the long lead support required to define the technology feasible development planning. The SRT information developed feeds into the simulation demonstration testing activity, which provides the means for discriminating between technologies and selecting a preferred development approach. The recommended SRT activity has been planned as a function to SPS development needs. However, a projection of Shuttle needs may reduce, by similarity, the development required for sensors.

If past trends continue, rendezvous and docking activities will become more frequent in coming years. They will be performed by launch vehicles, orbital transport vehicles, and a wide variety of other operational spacecraft. The most feasible long range plan is one that will emphasize a universal concept built of common flight hardware based on a single integrated technology development plan rather than several independent approaches. Economic efficiency and operational reliability can be achieved if adequate requirements are established and a thorough development process is implemented.

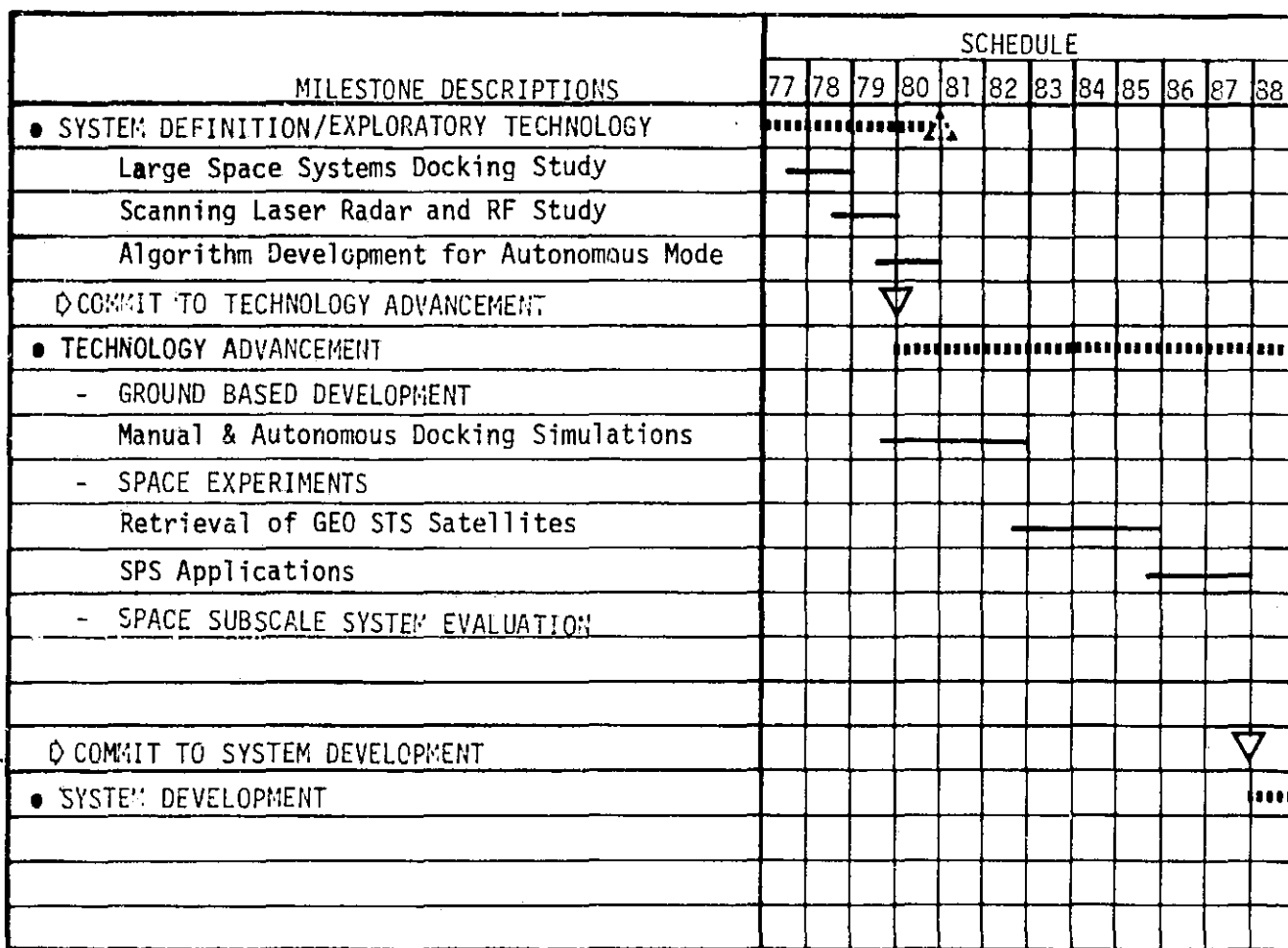


Figure 5.2.2-10 Docking System Development Schedule

5.2.3 Manned Cherry Picker

5.2.3.1 Introduction - A manned cherry picker is a vehicle which, through the use of articulated booms attached to structure, positions its bucket (which carries the operator and his equipment) as directed by the operator's controls. It can be used as a platform for many tasks. Figure 5.2.3-1 shows the evolution of cherry pickers as ranging from an open platform to a canned unit with manipulator arms.

5.2.3.2 Operational Description - All previous experience with manned cherry pickers has been from ground based units. These, however, have been greatly hindered from reaching their potential dexterity by gravity (due to tipping moments). Figure 5.2.3-2 shows the operational limitations of a ground based, 10-meter, articulating boom type cherry picker. A cherry picker used in space would not be constrained by gravity and therefore would have a larger reach envelope. Figure 5.2.3-3 compares the spheroidal reach envelope of a ground based cherry picker to the cardioid reach envelope of a cherry picker of the same size but operated in space.

Applications of cherry pickers in SPS construction could include the installation of turbogenerators and ducts in the Boeing Thermal SPS (see Figure 5.2.3-4), monitoring transportation and directing installations of large items (e.g., switch gears on MPTS, see Figure 5.2.3-5), and performing tasks to support automatic construction equipment.

5.2.3.3 Crew Participation - As a design guideline, cherry pickers should accommodate one crewman during operation, but should include the capability to transport two crewmen for rescue procedures. In order to conform to the study guideline concerning EVA (paragraph 1.5e), it is assumed that cherry pickers will operate in pairs where required, in close proximity to each other.

The cherry picker operator will control the movements of the bucket by the use of one or two "joy sticks". There are six basic movements that the bucket would perform: 1) revolution about the base-turntable; 2) translation perpendicular to the base-turntable; 3) translation parallel to the base-turntable; 4) rotation about three axes through the bucket.

5.2.3.4 Concepts - If the distance from the base-turntable to the work-site is great, it might prove feasible to use several small cherry pickers attached to one gross positioning boom as shown in Figure 5.2.3-6.

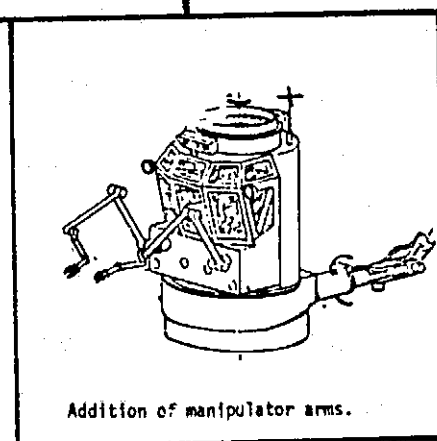
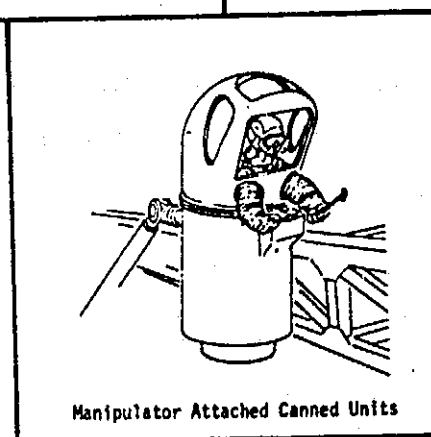
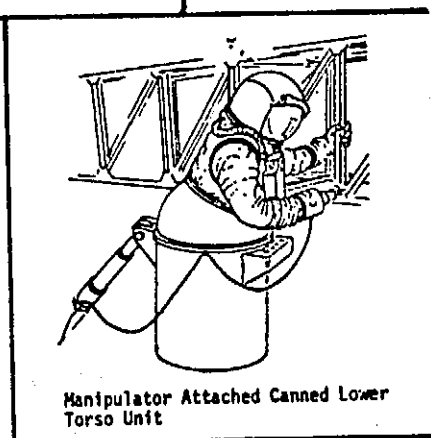
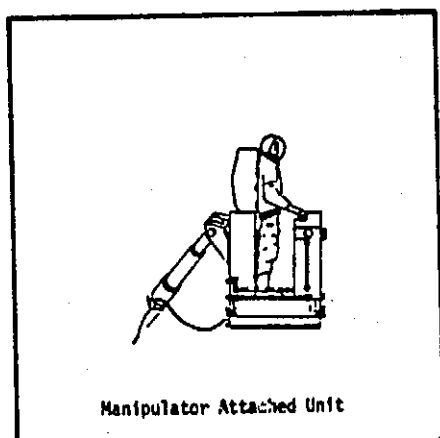


Figure 5.2.3-1 Evolution of Manned Cherry Pickers

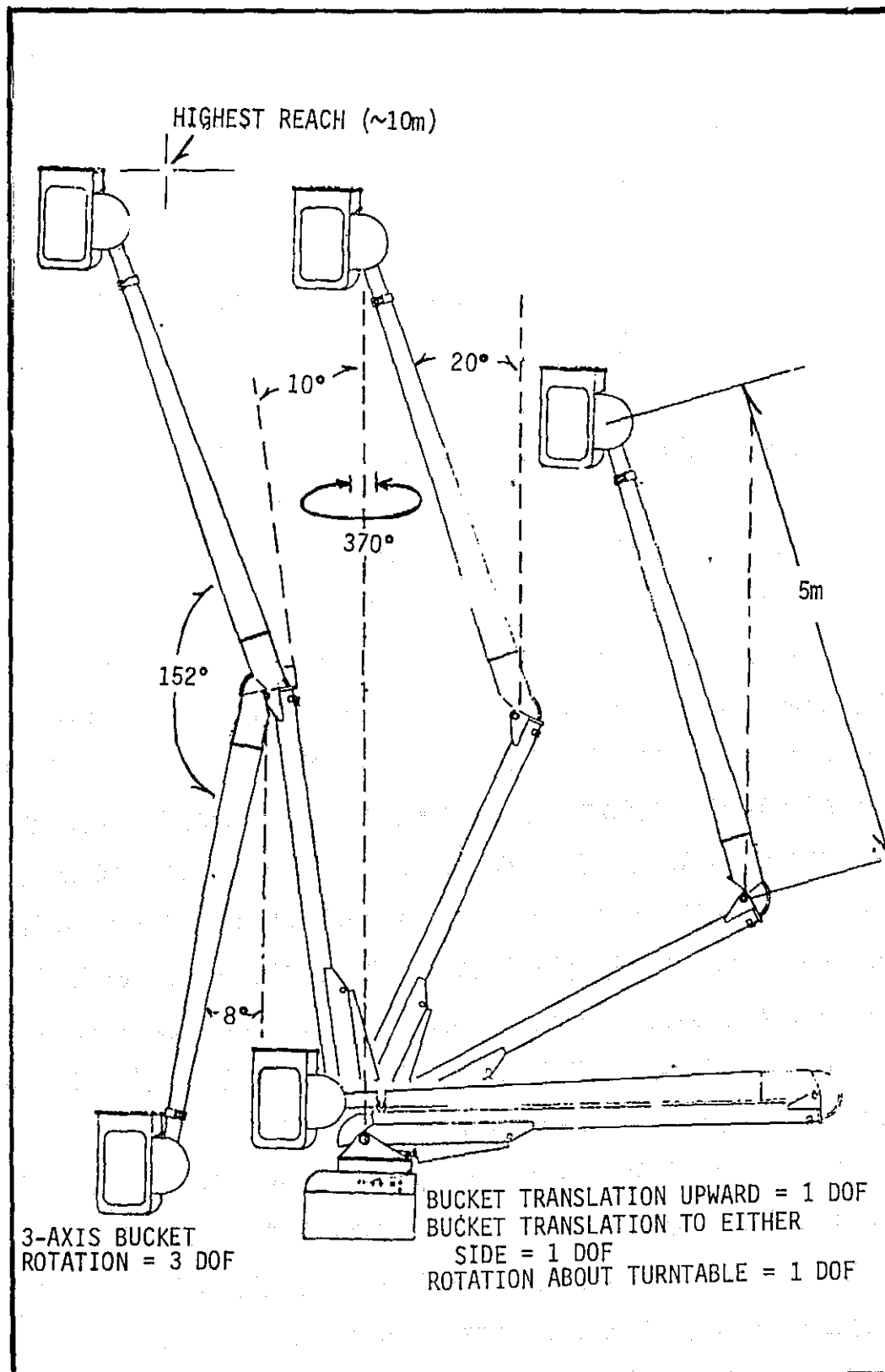


Figure 5.2.3-2 Operational Limitations of 10-meter Articulated Boom Type Cherry Picker

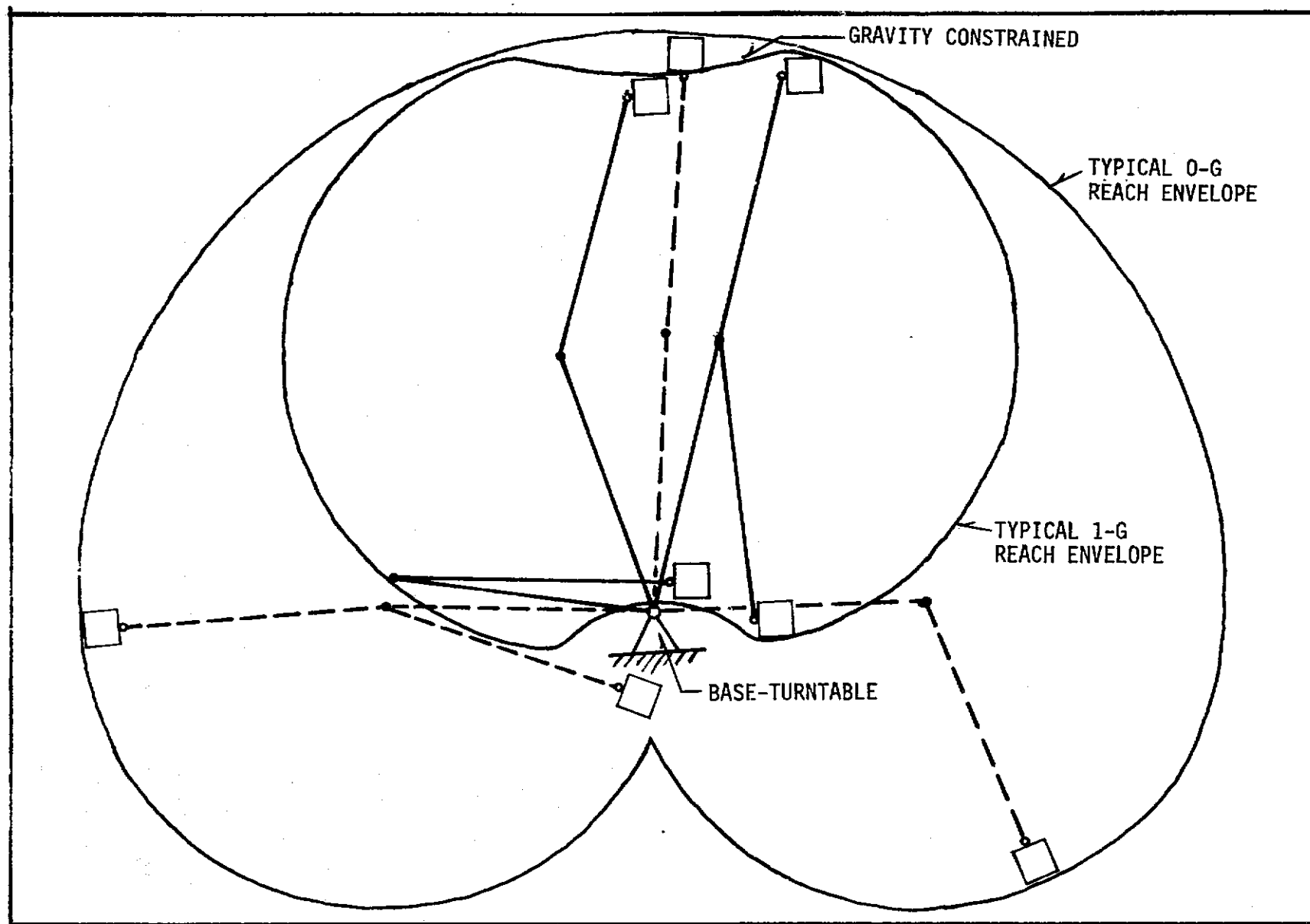


Figure 5.2.3-3 1-g and 0-g Reach Envelopes of an Articulated Boom Type Cherry Picker

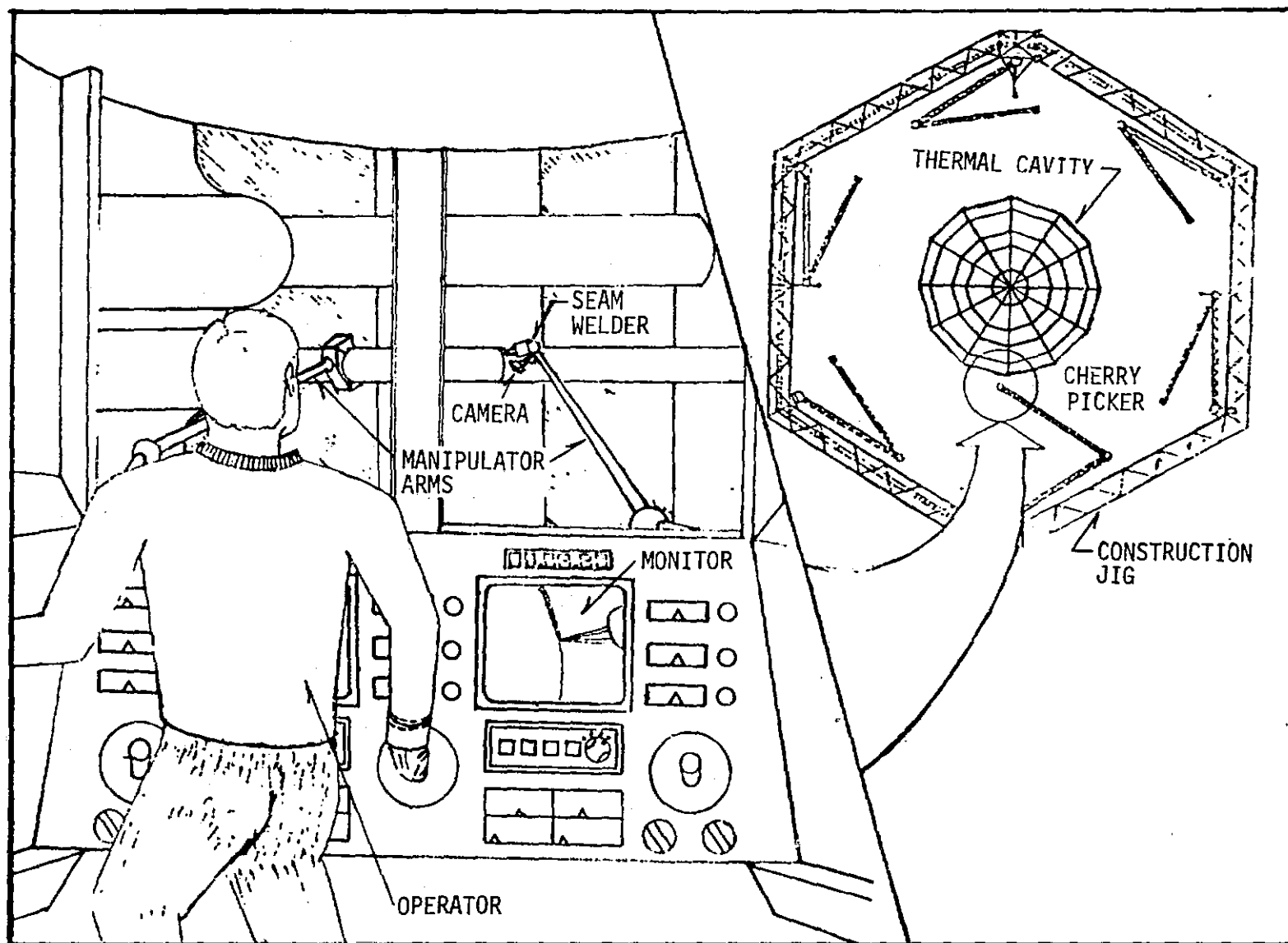


Figure 5.2.3-4 Canned Cherry Picker with Manipulator Arms Installing Turbogenerators

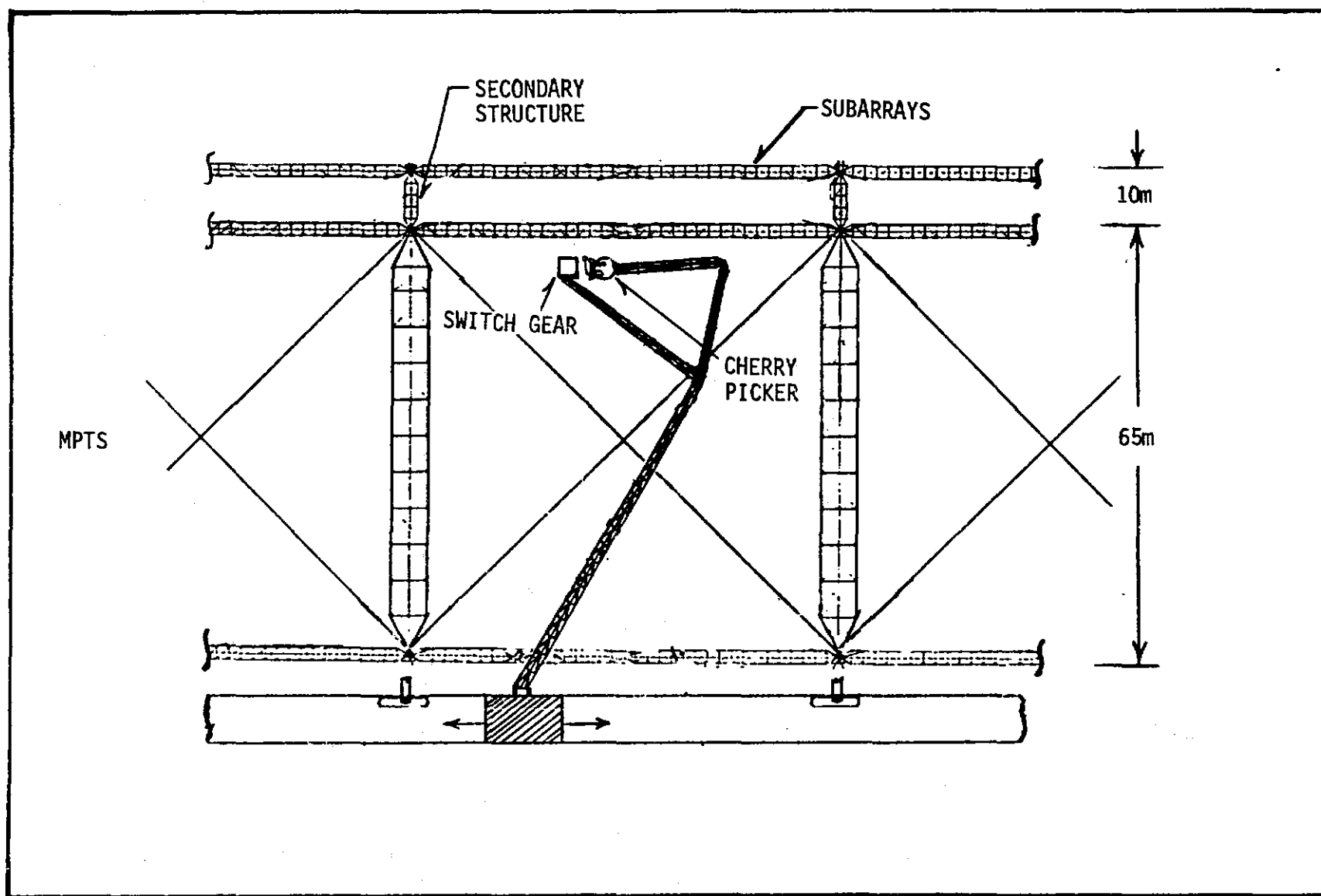


Figure 5.2.3-5 Cherry Picker Monitoring Transportation and Installing Switch Gears

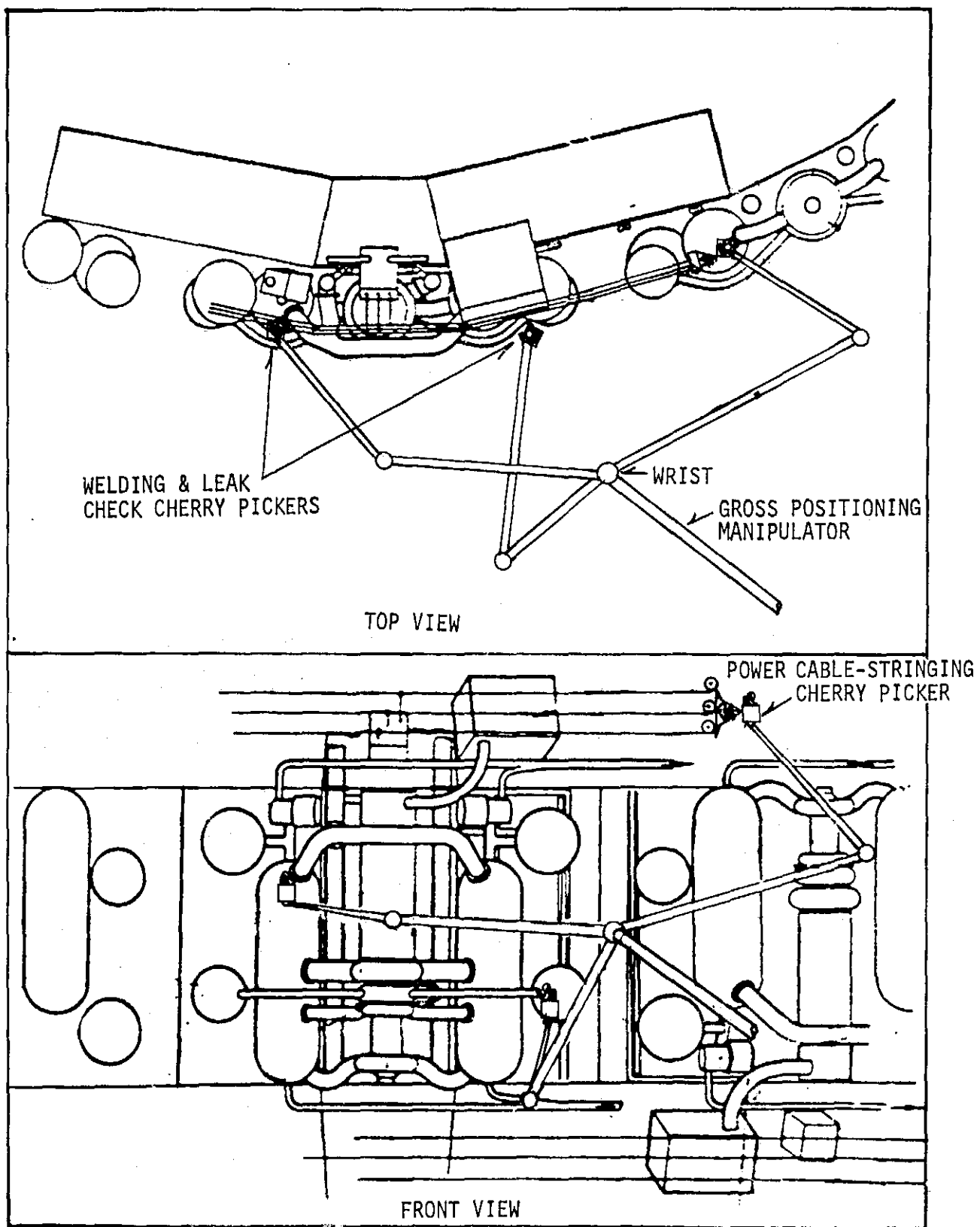


Figure 5.2.3-6 Cherry Picker Triad (Installing Boeing Turbogenerators)

The bucket of the cherry picker could evolve into a free flyer with the additions of a strap-on propulsion unit and a docking interface between bucket and boom.

Shown in Figure 5.2.3-7 is a concept in which the cherry picker is attached to a beam-riding vehicle. Forces and torques from the cherry picker booms are transferred directly to the beam under the vehicle through the triangular beam integrated in the vehicle's structure. The bucket is also shown having an integrated triangular beam to transfer loads.

5.2.3.5 Subsystems - The interface between the bucket and boom should be designed to permit rotation of the bucket about three axes. If the bucket is to be removed periodically, a docking device might be employed in the interface.

A power pick-off at the bucket, as shown in Figure 5.2.3-8, could support electrical tools used by the operator.

Controls and displays will be chosen to compliment the task to be done and should include bucket positioning controls, attitude hold controls, controls for manipulator arms, TV monitors, and displays for subsystems.

To simplify the task of controlling the cherry picker and to prevent possible damage to surrounding structure, the cherry picker booms and their connections should have collision avoidance equipment.

Communication links will be needed between the bucket and the dispatching station and from bucket to bucket as needed. A network must be constructed to supply the cherry picker with electrical power or, if it is self-supporting, the cherry picker must carry its own power. Table 5.2.3-1 is a performance summary of a manned cherry picker showing system characteristics and control characteristics.

5.2.3.6 Environmental Factors - Environmental factors affecting design of manned cherry pickers are included in Table 5.2.3-2.

5.2.3.7 Interface Considerations - If the cherry picker is launched as a package, it may be necessary to package it in sections that can be easily assembled on orbit. The bucket of the cherry picker and the motorized joints and turntable are compact units and should present no large stowing problems. The booms, however, with their small package density, cannot be

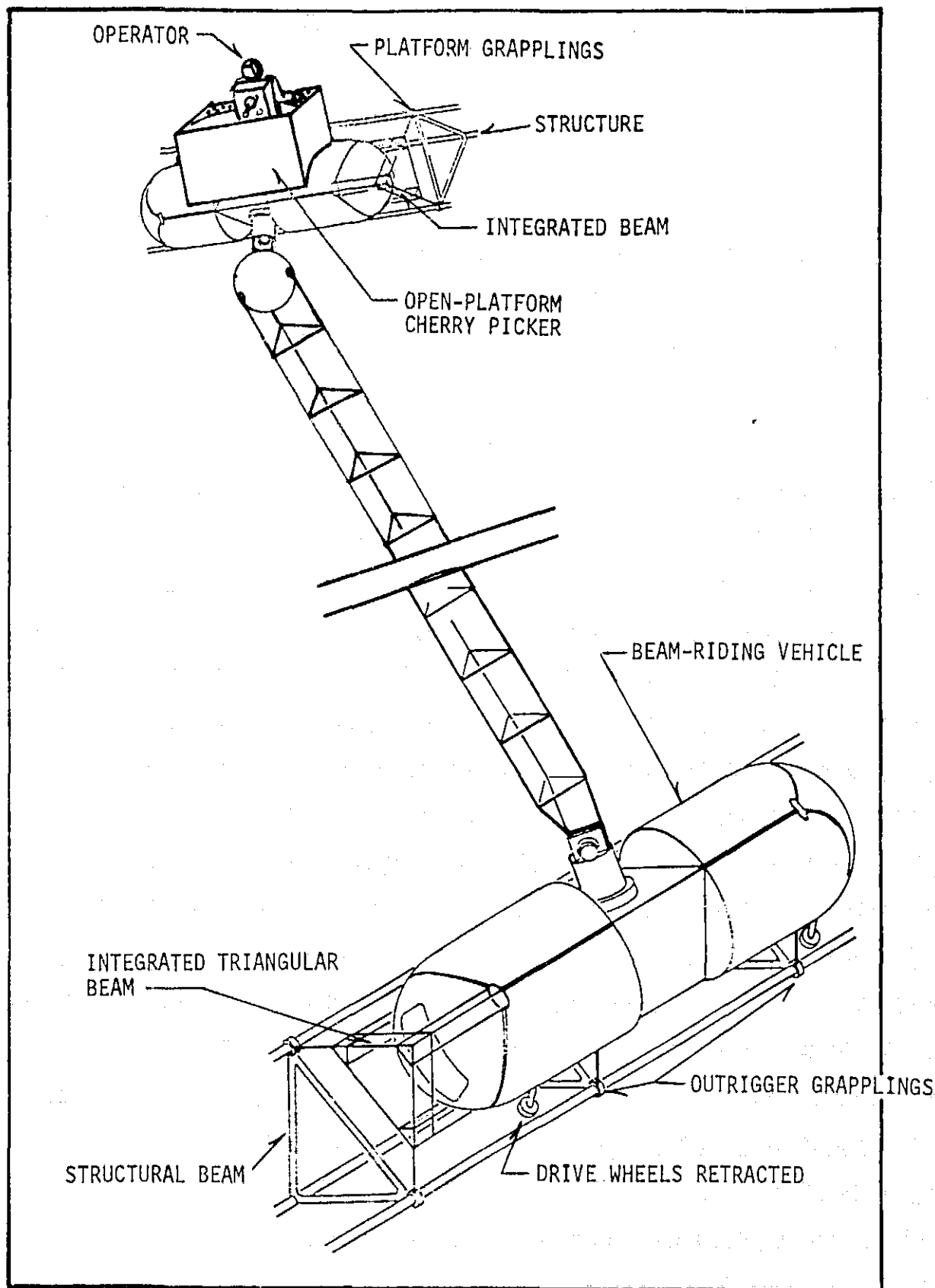


Figure 5.2.3-7 Method of Transferring Loads

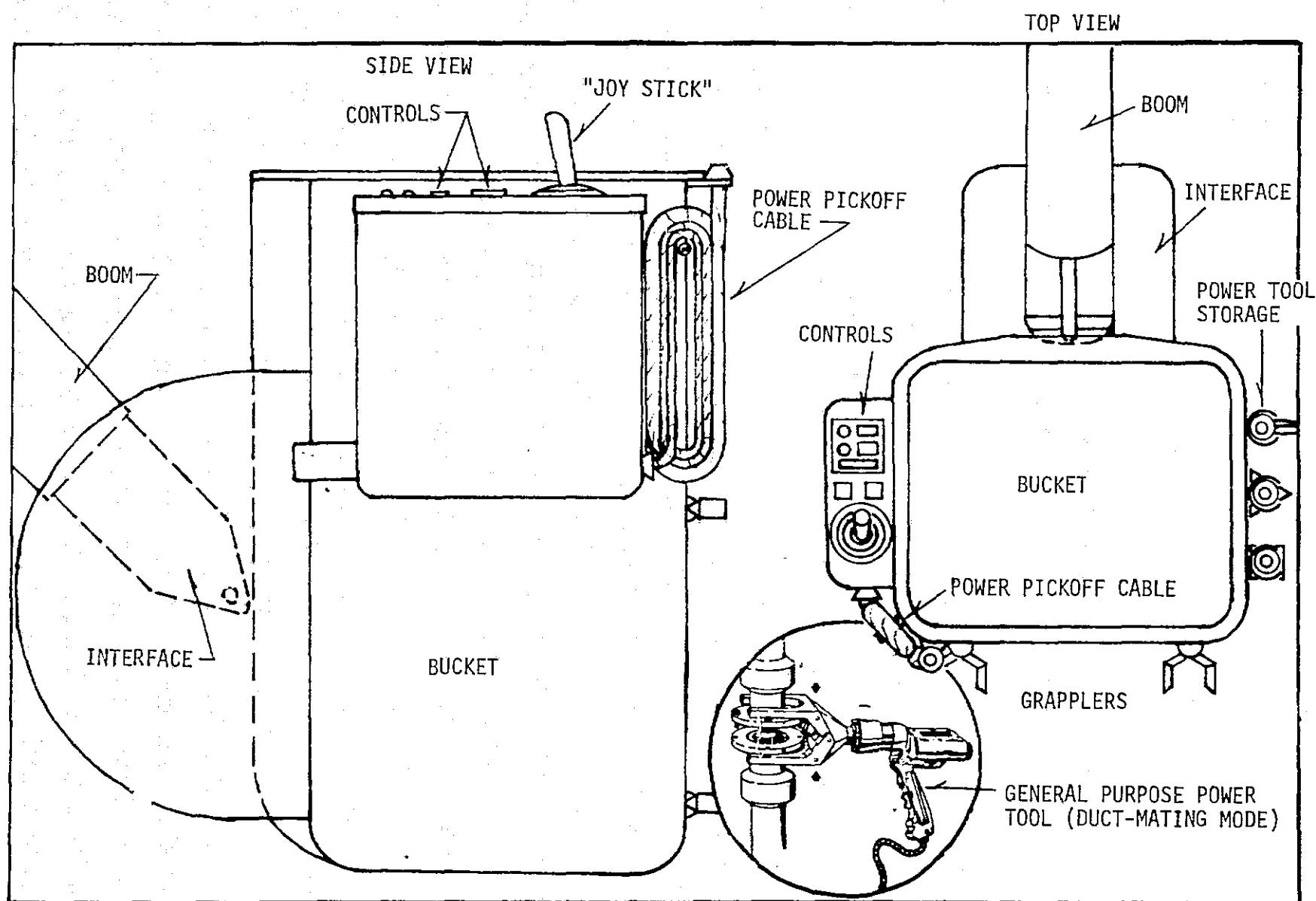


Figure 5.2.3-8 Cherry Picker Bucket

Table 5.2.3-1 Manned Cherry Picker Performance

- System Characteristics
 - Support 8-hour Work Task
 - Power for Locomotion, Tools, and Instruments
 - Life Support for 12 Hours
 - Noncontaminating
 - Interface with Dispatching Station
 - Weight ~800 Pounds (Bucket)
 - Length
 - 135 meters (typ for Boeing Thermal Cavity)
 - 75 meters (typ for MPTS)
- Control
 - Rotational, Revolutionary, and Translational Hand Controllers in Bucket to Input Maneuvering Commands
 - Six Degree of Freedom Control Authority Provided
 - Translation
 - 2-axis Acceleration Command
 - ft/sec maximum ΔV
 - ft/sec minimum ΔV
 - Rotation
 - 3-axis Acceleration Command
 - $8^\circ/\text{sec}^2$ Angular Acceleration
 - $0.5^\circ/\text{sec}$ Minimum Δ Rate
 - Revolution
 - 1-axis Acceleration Command
 - $8^\circ/\text{sec}^2$ Angular Acceleration
 - $0.5^\circ/\text{sec}$ Minimum Δ Rate
 - Automatic/Manual Attitude Hold
 - Automatic Drive Motor Locks
 - Manual Grapplings on Bucket

Table 5.2.3-2 Factors Affecting Design of Manned Cherry Picker

- Number of crewmen supported
- Work duration
- Metabolic work load
- Thermal loads
- Environmental factors
 - Radiation
 - Micrometeoroid
 - Thermal
 - Occular
- Equipment
 - Stowage/Interfaces
 - Tools/Aids Required
- Communications
- Controls and Displays
- Required Mobility/Dexterity
- Required Visibility
 - Lighting
 - Rear Viewing Devices
 - Mirrors
 - View Ports
- Interfaces
 - Cherry Picker to Worksite
 - Cherry Picker to Dispatching Station
- Food, Water, Waste Management

efficiently launched. Because of this, it may be necessary to fabricate the booms in orbit using one of the proposed beam builders and assemble the cherry picker using the manipulators of the beam builder.

5.2.3.8 Development Plan - The future activities recommended in this area of technology are shown in Figure 5.2.3-9. The supporting research and technology areas identified are man/machine interactions with small dexterous manipulators; definition of the crew housing or cab portion of the cherry picker

which best meets tasks feasibility and SPS program compatibility; and radiation impacts on cab shielding and crew safety. The cab should be developed as a common hardware item since it has many applications with the same general requirements as other OCSE items which are required later in the development schedule. The task applications and radiation impacts are presently being worked under ECWS contract which is scheduled for completion in mid-1978. Some of the specific subsystems which require simulations/demonstrations includes crew transfer, cab/manipulator interface and operator/controls and displays compatibility. System development has been moved up to mid-1984 to be available for SPS Pilot Plant demonstrations based on the rationale that the 1985 configuration is projected to be the same for the 1995 era.

MILESTONE DESCRIPTIONS	SCHEDULE											
	77	78	79	80	81	82	83	84	85	86	87	88
● SYSTEM DEFINITION/EXPLORATORY TECHNOLOGY												
TASK APPLICATIONS STUDY (ECWS)	=====											
SYSTEM PRELIMINARY DESIGN STUDY		=====										
RADIATION IMPACT STUDY		=====										
◇ COMMIT TO TECHNOLOGY ADVANCEMENT			▽									
● TECHNOLOGY ADVANCEMENT												
- GROUND BASED DEVELOPMENT												
HUMAN FACTORS & CREW SAFETY DEVELOPMENT			=====									
- SPACE EXPERIMENTS												
MANIPULATOR TO CHERRY PICKER INTERFACE				=====								
AND UNMANNED OPERATION												
- SPACE SUBSCALE SYSTEM EVALUATION												
MANNED PERFORMANCE CAPABILITIES					=====							
DEMONSTRATION AND VERIFICATION (PPO&I)												
◇ COMMIT TO SYSTEM DEVELOPMENT											▽	
● SYSTEM DEVELOPMENT												
DESIGN, BUILD AND TEST FLIGHT OPERATIONAL						=====						
UNIT												

Figure 5.2.3-9 Cherry Picker Development Schedule

5.2.4 Central Hub Assembly/Deployment (CHAD) Module

5.2.4.1 Introduction - CHAD modules are facilities which contain the equipment (CE or OCSE) to fabricate and/or assemble the first section of SPS structure or SPS support structure in orbit. This initial construction can be part of the base facility (e.g., truss type SPS construction base), or part of the SPS itself (e.g., column/cable control hub; MPTS first concentric ring). It should be noted that the term CHAD module as used in this report implies more than a central docking facility to which other modules attach. As applied here, the term CHAD module implies an inherent fabrication/assembly capability. In its most basic form, it is similar in concept to the fabrication/assembly module as advanced by MDAC in an earlier study; however, more complex concepts of the CHAD module are also presented here.

5.2.4.2 Operational Discussion - For the purposes of this discussion, it is assumed that the CHAD module itself requires no assembly on orbit (although it may deploy equipment during the course of its activity) and can be launched as a single unit. Once in orbit the CHAD module fabricates beams and assembles them to achieve the required geometry. The CHAD module can be configured to fabricate beams and hold them until they are used by a manipulator system to build the desired shape (see Figure 5.2.4-1) or the manipulator system can work with the beam fabricators to build a deployable structure (see Section 5.2.4.4).

Examples of the potential applicability of CHAD modules are the construction of a cube (100 meters on a side) for the central hub of the column/cable SPS, the construction of a triangular wedge (~650 meters on a side) as part of the construction base of the truss type SPS, the construction of the extension structure for the MPTS, and the construction of the support arms and main substructure of the MPTS.

5.2.4.3 Crew Participation - Because the CHAD module is considered to be a compact unit which builds the very first section of the SPS structure, crew participation would be minimal.

5.2.4.4 Concepts - The CHAD module concept whose functions are most basic is represented in Figure 5.2.4-1. This core module (proposed by McDonnell Douglas) fabricates the beams and holds them until they are used by a manipulator system to form the desired shape.

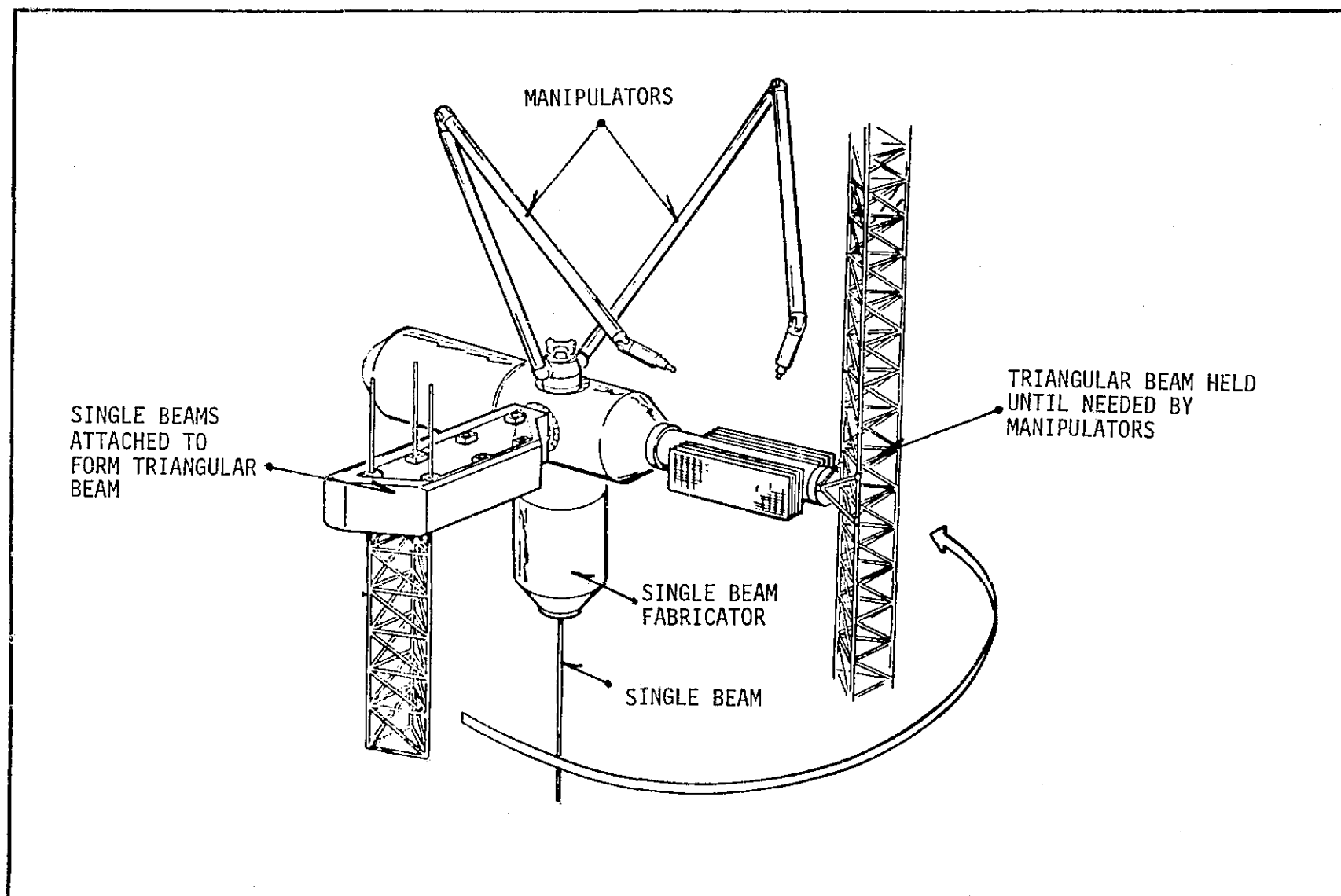


Figure 5.2.4-1 Basic Fabrication/Assembly Module

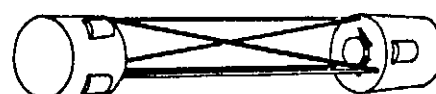
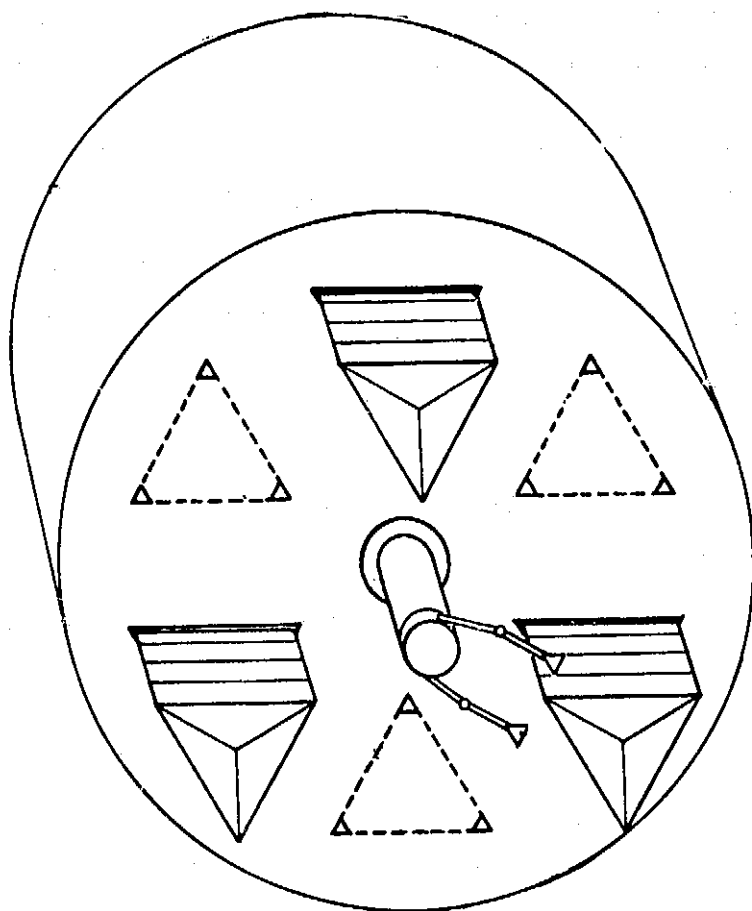


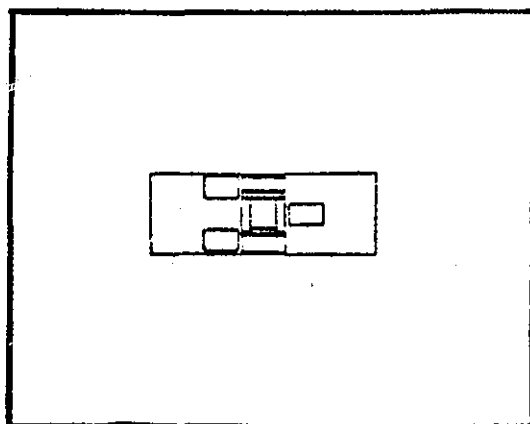
Figure 5.2.4-2 LAD Module

A CHAD module concept which builds and deploys three dimensional structures is the linear assembler/deployer (LAD) module (represented in Figure 5.2.4-2). This module is designed to fabricate and deploy a basic structure of designated geometry and dimensions (e.g., cube, triangular wedge). Each such module would be capable of constructing only one structure of a given type, and would have to be reconfigured to duplicate the structure at another location. Figure 5.2.4-3 shows the sequence of steps required to construct a cube structure. Figure 5.2.4-4 shows this sequence, giving more detail to the actual mechanics of such an operation. As the figures indicate, the CHAD module in this concept is actually composed of two identical halves which draw apart from each other as the beam members are fabricated. Actual deployment of the structure is accomplished by the reeling in of (active) cables by each module. Passive cables attached to the structure unreel as the deployment continues but, because of their finite length, stop the deployment when the desired shape is reached.

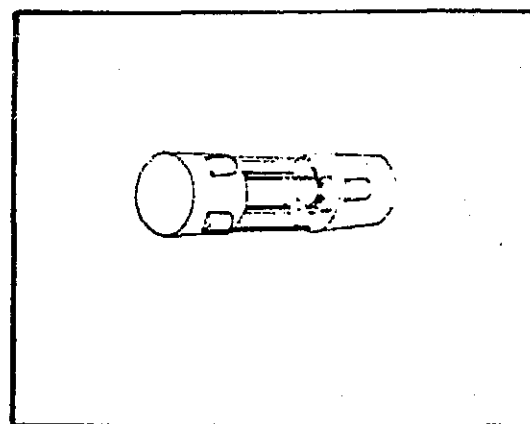
Another CHAD module concept which might be a unique OCSE system is the sequential traveling, assembler/deployer (STAD) module (shown in Figure 5.2.4-5). This module is designed to construct various structural elements of the SPS (i.e., extension structure, support arms and main substructure of the MPTS).

The STAD begins by constructing the extension structure in the method represented in Figure 5.2.4-6, moving outward as it does. Three of its six beam fabricators build the main extension structure beams, and the other three fabricate the cross members. Manipulators within the STAD assist in orienting the cross members and in fastening the beam ends at the joint. Support cables are also strung as part of the automatic assembly procedure. Once the extension structure is completed, the STAD module is moved from the end of the structure to a position on the surface of the structure, where it can proceed with construction of the first concentric ring and support arms. Figure 5.2.4-7 depicts the sequence of steps by which assembly of the concentric ring radial members is accomplished. Further construction steps are required to assemble the support arm structure underneath the first concentric ring, and to attach the entire assembly to the joint. Once these steps have been completed, the STAD module continues to fabricate MPTS frames for assembly into the second, third, and fourth concentric rings.

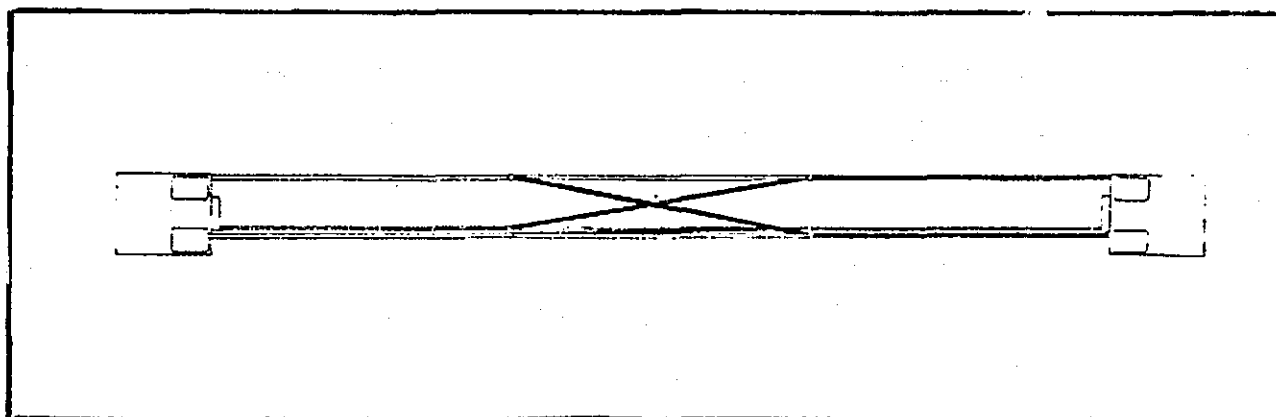
5.2.4.5 Subsystems - Subsystems on the CHAD module of Figure 5.2.4-1 include a single-beam fabricator, triangular beam construction equipment, two beam manipulators, and triangular beam holding equipment.



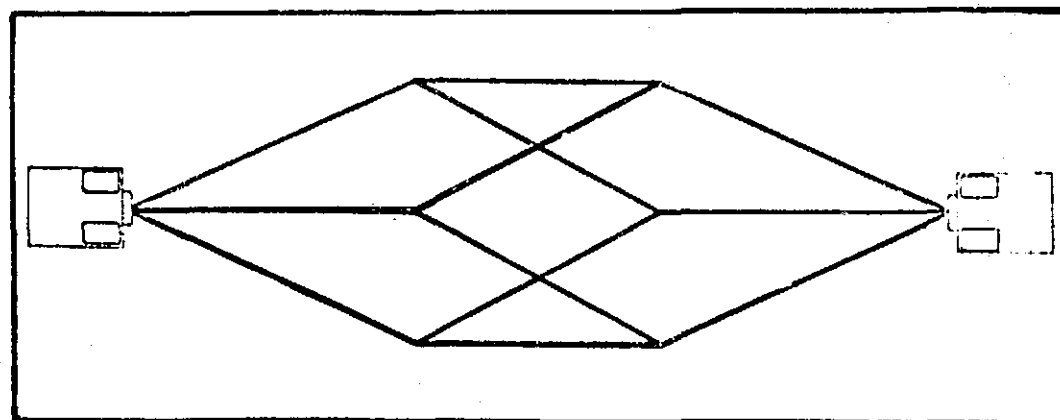
STEP #1 Two CHAD modules face to face. Coincides with Step #1 of Figure 5.2.4-4. Cables not shown for clarity.



STEP #2 CHAD modules move apart as each fabricates 3 beams.



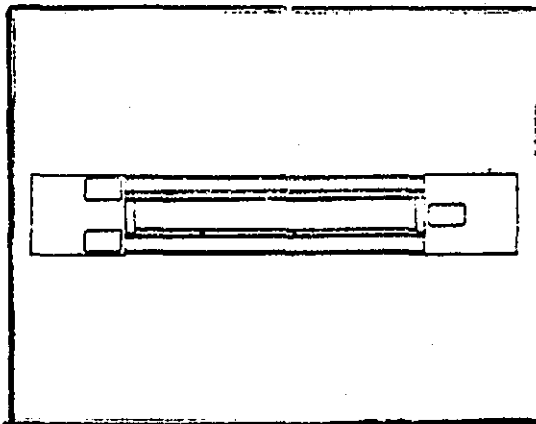
STEP #5 CHAD modules continue to move away from each other as each fabricates three more beams. CHAD modules shown here having completed these beams (100m). Coincides with Steps #6 & 7 of Figure 5.2.4-4.



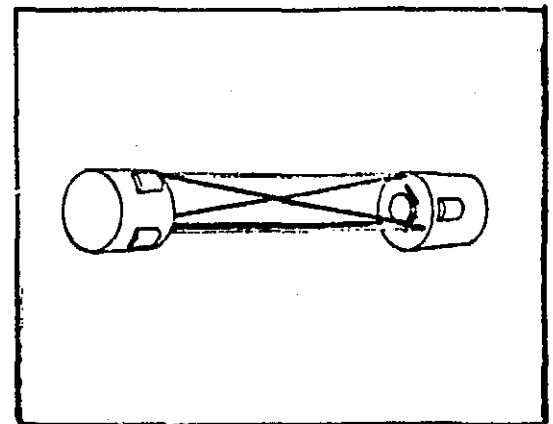
STEP #7 CHAD modules fabricate cables to form cube with Step #9 of Figure 5.2.4-4.

STEP #8 CHAD modules having completed free for other jobs cube self-support with Step #10 of Figure 5.2.4-4.

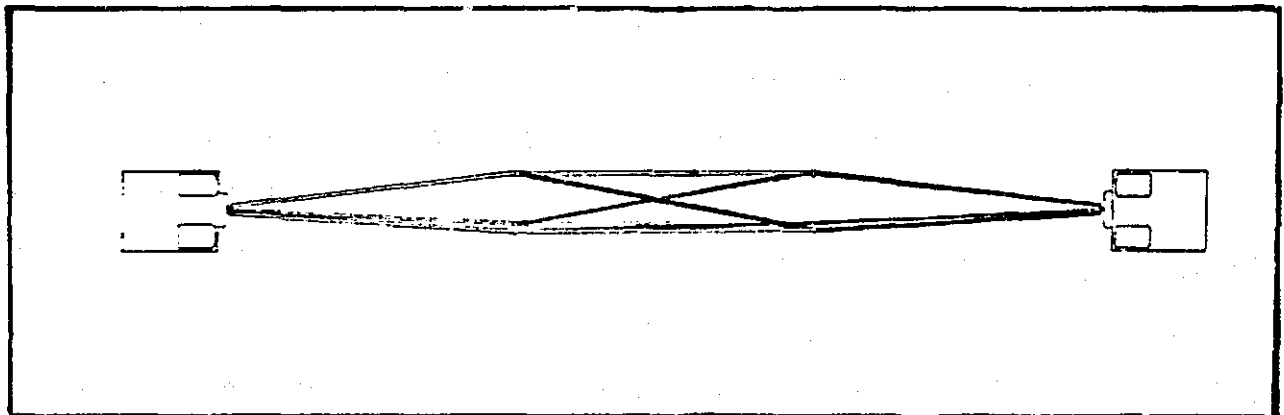
Figure 5.2.4-3 LAD Module Construction Cube



STEP #3 CHAD modules having completed first six 100 meter beams. Coincides with Step #2 of Figure 5.2.4-4.



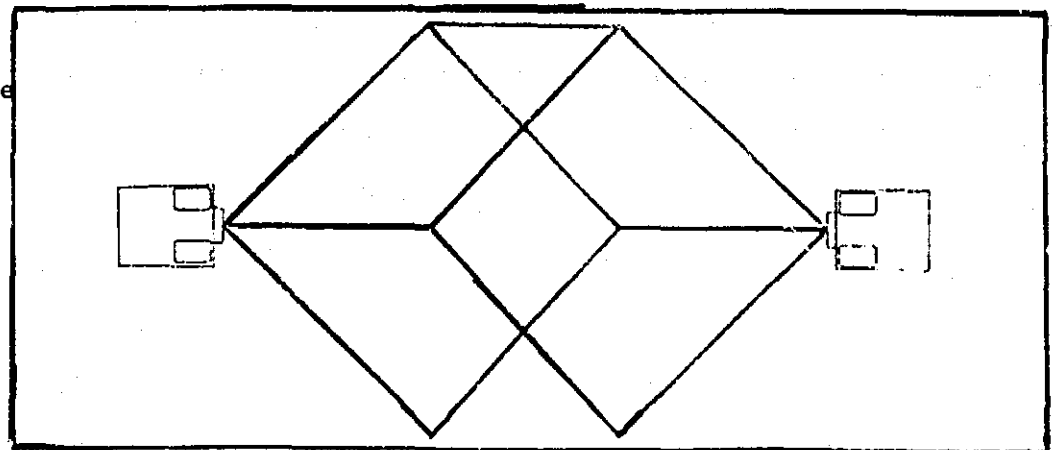
STEP #4 Six beams are attached as shown. Coincides with Steps #3, 4 & 5 of Figure 5.2.4-4.

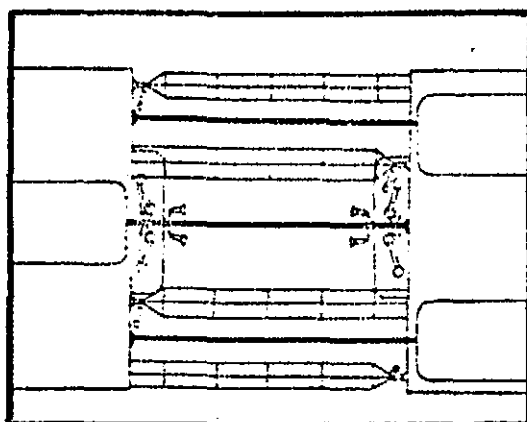


STEP #6 New beams are joined as shown. Coincides with Step #8 of Figure 5.2.4-4.

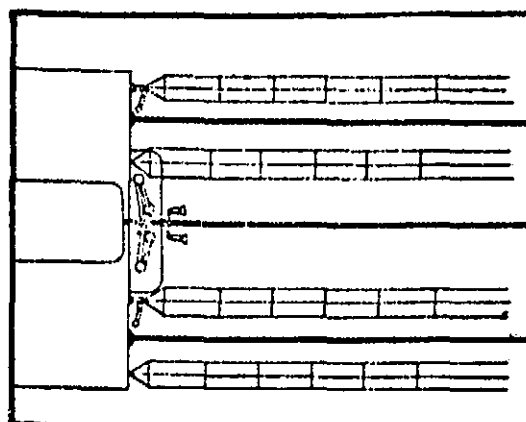
STEP #7 CHAD modules reel in active cables to form cube. Coincides with Step #9 of Figure 5.2.4-4.

STEP #8 CHAD modules shown here having completed cube. Modules are free for other jobs after making cube self-supporting. Coincides with Step #10 of Figure 5.2.4-4.





NOTE: For clarity, only 2 of 3 beams & 2 of 3 cables are shown at each CHAD module.

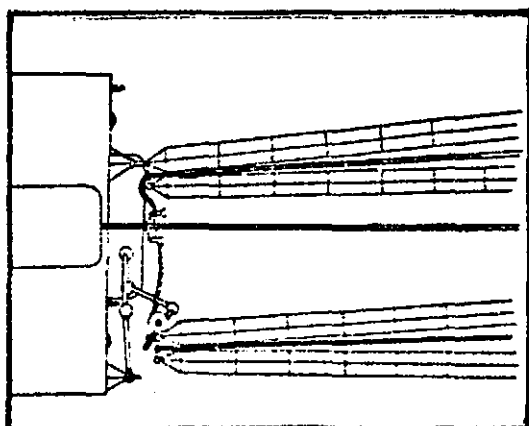


Each CHAD module performs identical step; only one side shown

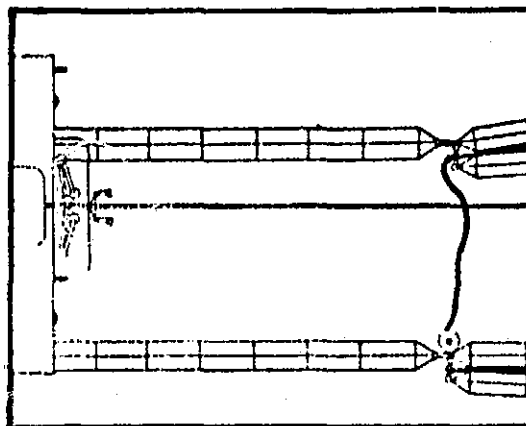
STEP #1. Two CHAD modules face to face. Each CHAD module is attached to the three beams being fabricated by the other CHAD module. Each CHAD module is attached to three cables reeled out from the other CHAD module.

STEP #2. As CHAD modules fabricate beams each moves away from the other. Shown is one CHAD module after fabricating three beams the length of one edge of the cube that is being made. The joint ends have been fastened to these beams.

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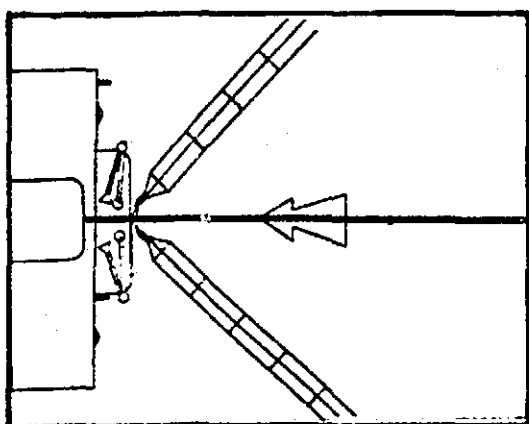


STEP #5. Each joint made in Step #3 is fastened to one of the three new beams being fabricated by the CHAD module.



STEP #6. Each CHAD module continues to fabricate three beams and continues to move away from each other. Each CHAD module continues to reel-out three cables.

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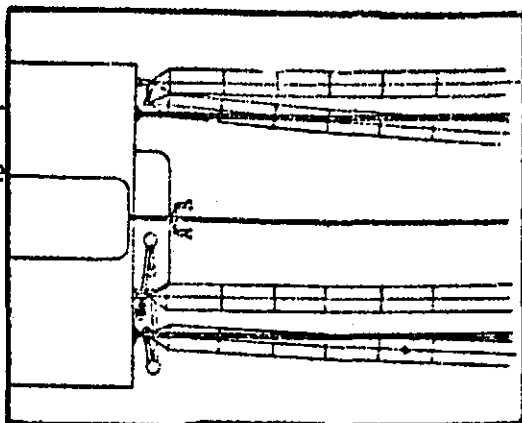


STEP #9. Each CHAD module reels in its three active cables less the length of one diagonal of the cube being made. As the cables are reeled in, the cube forms.

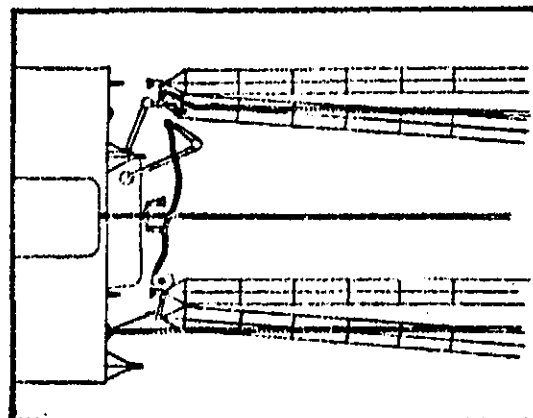


Figure 5.2.4-4 Cube Construction Details

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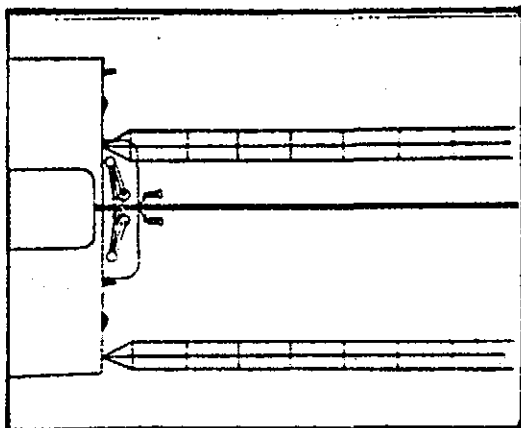


STEP #3. The three beams fabricated by the CHAD module in the drawing are being attached to the three beams fabricated by the other CHAD module by the manipulators as shown.

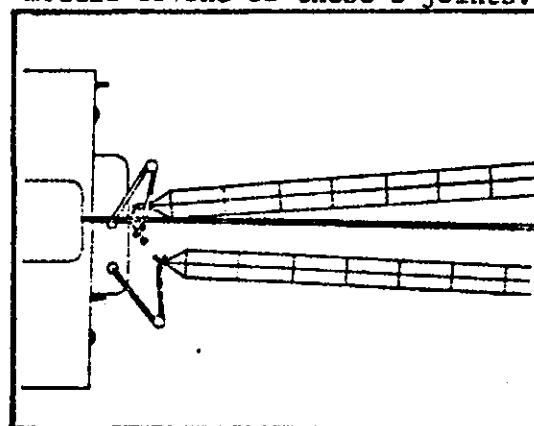


STEP #4. The joints made in Step #3 are released from the CHAD modules and are connected to each other with 3 reels of passive cable. The CHAD module attaches each of the 3 cables from the other CHAD module to one of these 3 joints.

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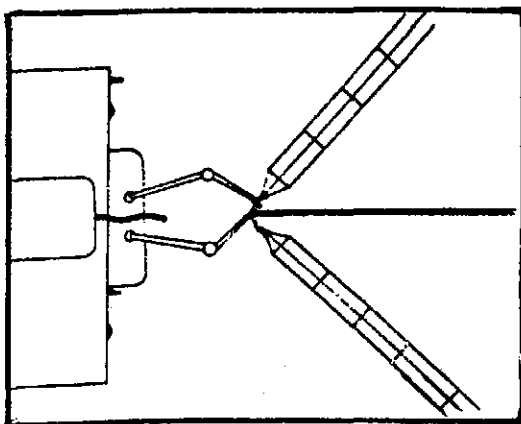


STEP #7. Each CHAD module fabricates its three new beams the length of one edge of the cube being made. Joint ends are fastened to each beam.



STEP #8. Each CHAD module fastens its three beams to a three member joint with its manipulators.

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STEP #10. After having made the cube each CHAD module fastens its three cables to the three-member joints making the cube self-supporting. The CHAD modules now are free to help with other construction.

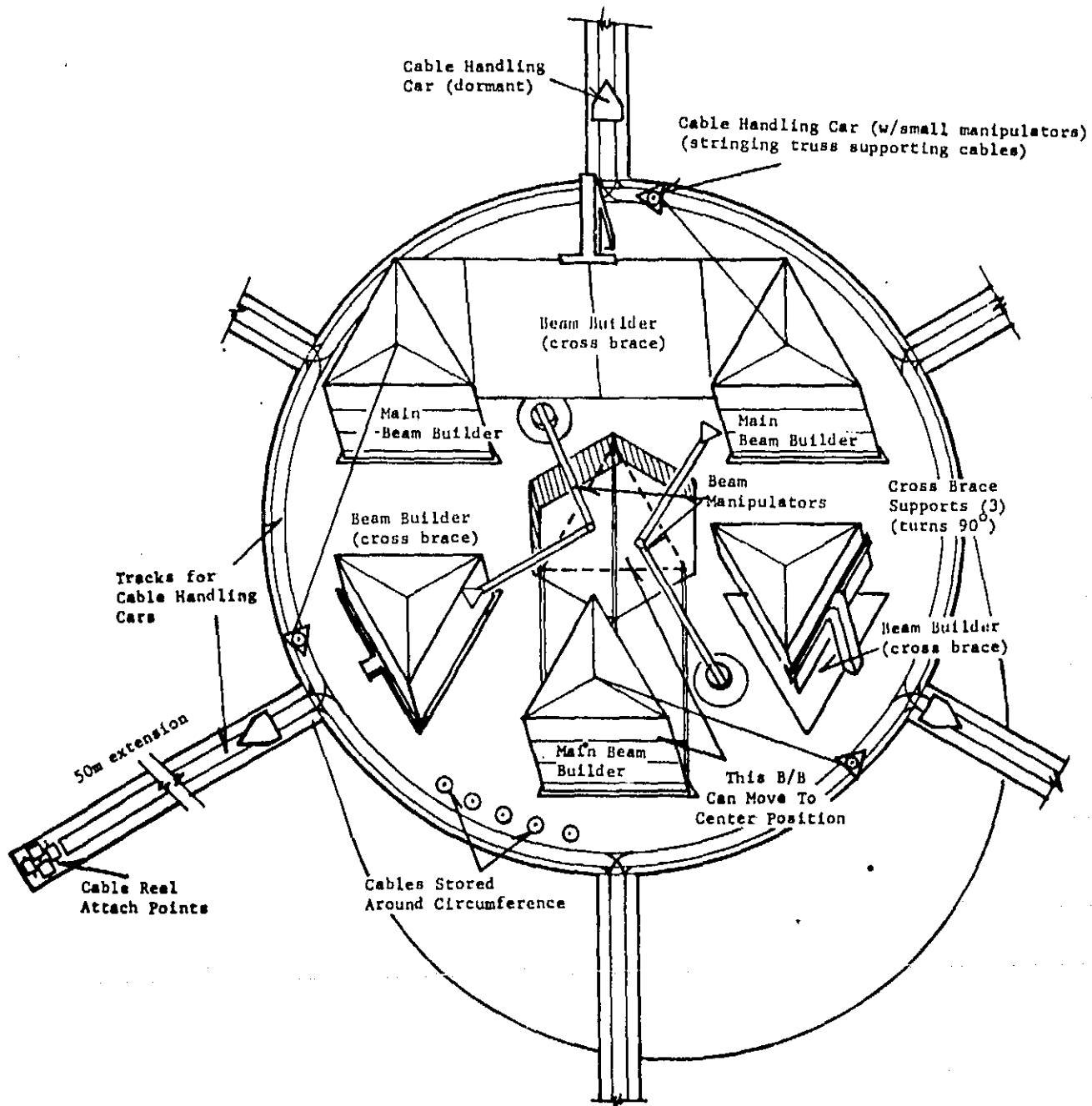


Figure 5.2.4-5 STAD Module

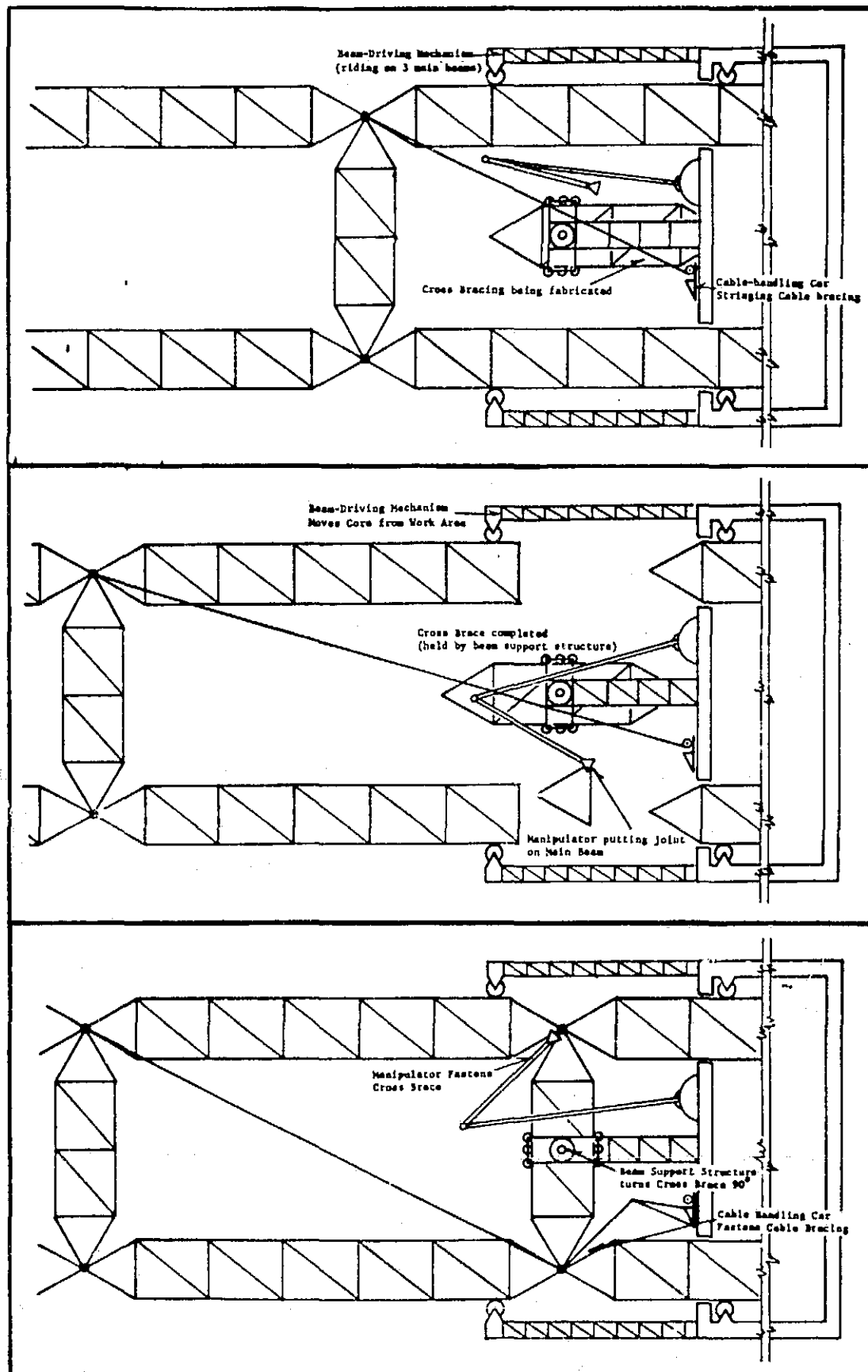
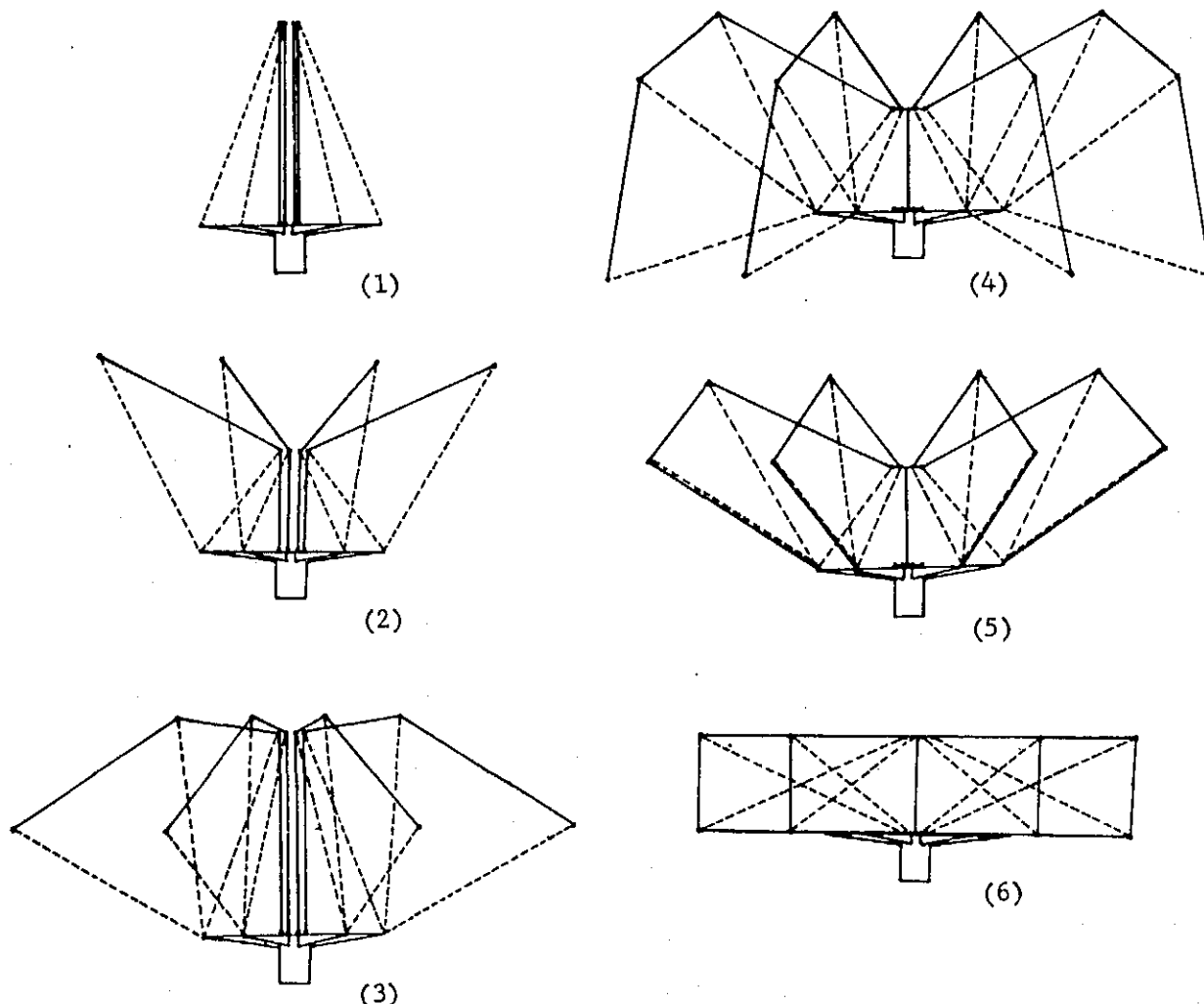


Figure 5.2.4-6 STAD Module Building Extension Structure



Sequential Traveling Assembler/Deployer Module in Concentric Ring Mode

STEP #1 First six 130-meter beams constructed (4 shown). 140 meter cables (dotted lines) attached from beam ends to 50 meter extensions.

STEP #2 As 60-meter beams are fabricated, cables direct 130-meter beams as shown. 140 meter cables attached to 60-meter beams.

STEP #3 As 130-meter beams are fabricated, cables direct 60-meter and first six 130-meter beams as shown. 140 meter cables attached as shown.

STEP #4 One beam-builder moves to center position to construct central hub. 140 meter cables attached as shown.

STEP #5 First six 130-meter beams are reeled-in with cables. Cables from opposite corners are connected to each other.

STEP #6 All cables are tightened to form concentric ring as shown.

Figure 5.2.4-7 STAD Module Constructing 1st Concentric Ring

Subsystems on the LAD module are more complex. The triangular beams are fabricated as complete units by beam fabricators. Fifteen meter long manipulators mounted on a turret make all the beam and cable connections. Cable deployment and drive mechanisms handle the cable support and deployment procedures. The joints connecting the triangular beams must be capable of rotation about several axes during the deployment phase and then must lock in the final position once the desired structure shape is achieved. Figure 5.2.4-8 shows the required rotations for the applicable joint locations in the final structure.

The subsystems on the STAD module are the most complex of the subsystems of the three concepts. Besides having triangular beam builders and 15-meter dual manipulators as in the LAD module, it also has six small cable handling cars, riding on tracks around the circumference of the module which string support cables between beams (for extension structure cross struts). These cars also ride tracks on the six 50-meter extension arms radiating from the module. These extensions are utilized during assembly of the MPTS concentric ring radial members. A support structure extends longitudinally (the long axis of the STAD) from each main beam fabricator outside the module to support the STAD and drive it back along the completed structure. Similar supports are used along each cross brace beam fabricator axis; a drive system mounted at the end of each support allows the cross trusses to be rotated through 90° for attachment between the main beams of the extension structure. Finally, during construction of the radial members of the first concentric ring, one of the main beam builders moves to the center position in the module to fabricate the central hub beam.

5.2.4.6 Environment Factors - Because the CHAD module will be a self-supporting unit, it will have to be designed so as to protect its construction equipment against damage by space exposure.

5.2.4.7 Interface Considerations - It is assumed that the CHAD module requires no assembly on orbit. It is further assumed that the CHAD module is of a size (20-meter diameter x 30-meter length, maximum) and mass that can be launched as a unit by a heavy lift launch vehicle (HLLV). The CHAD module can be conceptualized either to remain in place as an inherent part of the structure once its fabrication/assembly task is complete, or it can be removed to a new construction site to repeat the procedure.

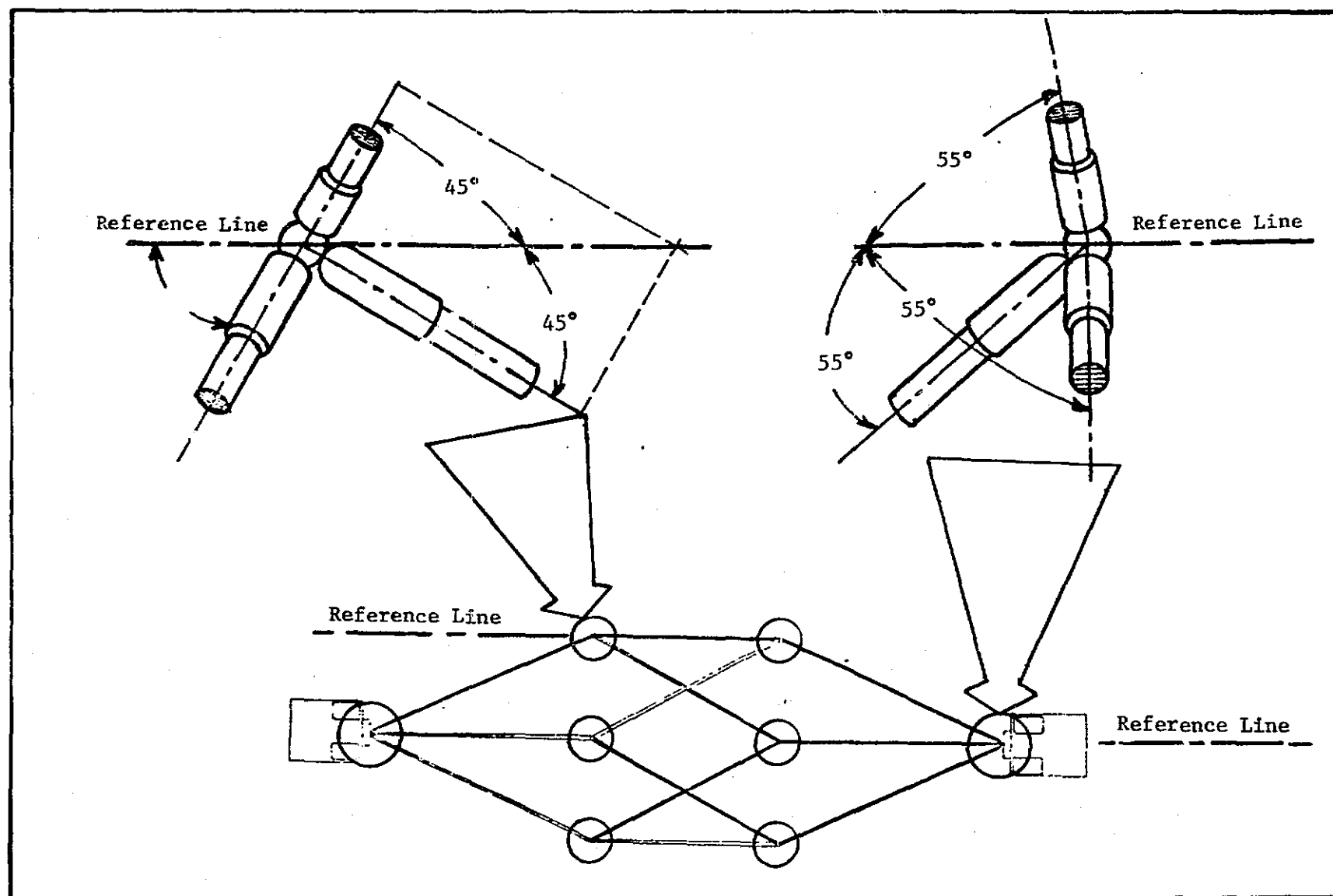


Figure 5.2.4-8 Required Rotations for Joints of Cubic Core

5.2.4.8 Development Plan - The development of the control hub assembly deployment module is closely related to the SPS development plan. Present planning indicates that the CHAD will be developed in steps, starting with the assembly of structural elements, assembly and integration of subscale systems, and assembly and integration of an interim sized SPS. The primary drivers in the development plan are the launch vehicles such as Shuttle, OTV, and HLLV, and the early plans for large space structures such as the Pilot Plants for SPS demonstrations, construction base demonstrations, Teleoperator Space Spider demonstration, etc. The development and implementation of the CHAD must be responsive to all planned large space structures programs in a cost effective manner, not piecemeal by individual program contractors. The planning approach used here assumed a CHAD evolution of three basic generations prior to commitment to the 1995 CHAD configuration. The future activities recommended to start this effort are shown in Figure 5.2.4-9.

MILESTONE DESCRIPTIONS	SCHEDULE											
	77	78	79	80	81	82	83	84	85	86	87	88
● SYSTEM DEFINITION/EXPLORATORY TECHNOLOGY												
- CHAD PRELIMINARY DESIGN STUDY				—								
- MANUAL VS AUTONOMOUS COST. SCENARIO		—										
◇ COMMIT TO TECHNOLOGY ADVANCEMENT				▽								
● TECHNOLOGY ADVANCEMENT												
- GROUND BASED DEVELOPMENT												
DESIGN/BUILD & TEST PROTOFLIGHT UNIT					—							
- SPACE EXPERIMENTS												
SHUTTLE FLIGHT PERFORMANCE DEMONSTRATION						—						
- SPACE SUBSCALE SYSTEM EVALUATION												
SPS, PILOT PLANT 0						—	—	—				
SPS, PILOT PLANT I							—	—	—			
◇ COMMIT TO SYSTEM DEVELOPMENT												▽
● SYSTEM DEVELOPMENT												

Figure 5.2.4-9 Control Hub Assembly/Deployment Module Development Schedule

5.2.5 Fixed Base Long Boom

5.2.5.1 Introduction - A fixed-base long boom is defined as a general purpose handler having up to four degrees of freedom. It provides a means for transport of material and/or crew from one point to another.

5.2.5.2 Operational Description

5.2.5.2.1 General - The fixed-base boom has more limited flexibility and dexterity than the general-purpose manipulator systems, but is generally considerably longer and covers a far greater working envelope. It provides rapid material transfer with a minimum of control complexity.

Long-boom types include: 1) fixed in place which provides straight line (or curvilinear) transfer; 2) pivoted at one end which provides planar/surface coverage; and 3) pivoted at both ends and incorporating a release mechanism which provides mobility and enables broad coverage without requiring excessively long booms.

5.2.5.2.2 Applications - The long boom transporter has numerous applications in support of SPS construction. One primary application-dependent boom parameter is the length as shown in Table 5.2.5-1.

Table 5.2.5-1 Long Boom Length Requirements

APPLICATION	LENGTH
Column Cable Facility Support	100 - 200 m
Jig Construction	150 - 200 m
MPTS Construction	500 m
Truss Construction Facility Support	650 m
Boeing Thermal Facet Supply	Up to 2 km

The application requiring one of the longest booms is providing transfer and installation support for the secondary structure and thermal facets of the Boeing thermal SPS as illustrated in Figure 5.2.5-1. However, it should be noted that the transfer might occur across several shorter booms in series, or by providing additional supply points on the primary structure.

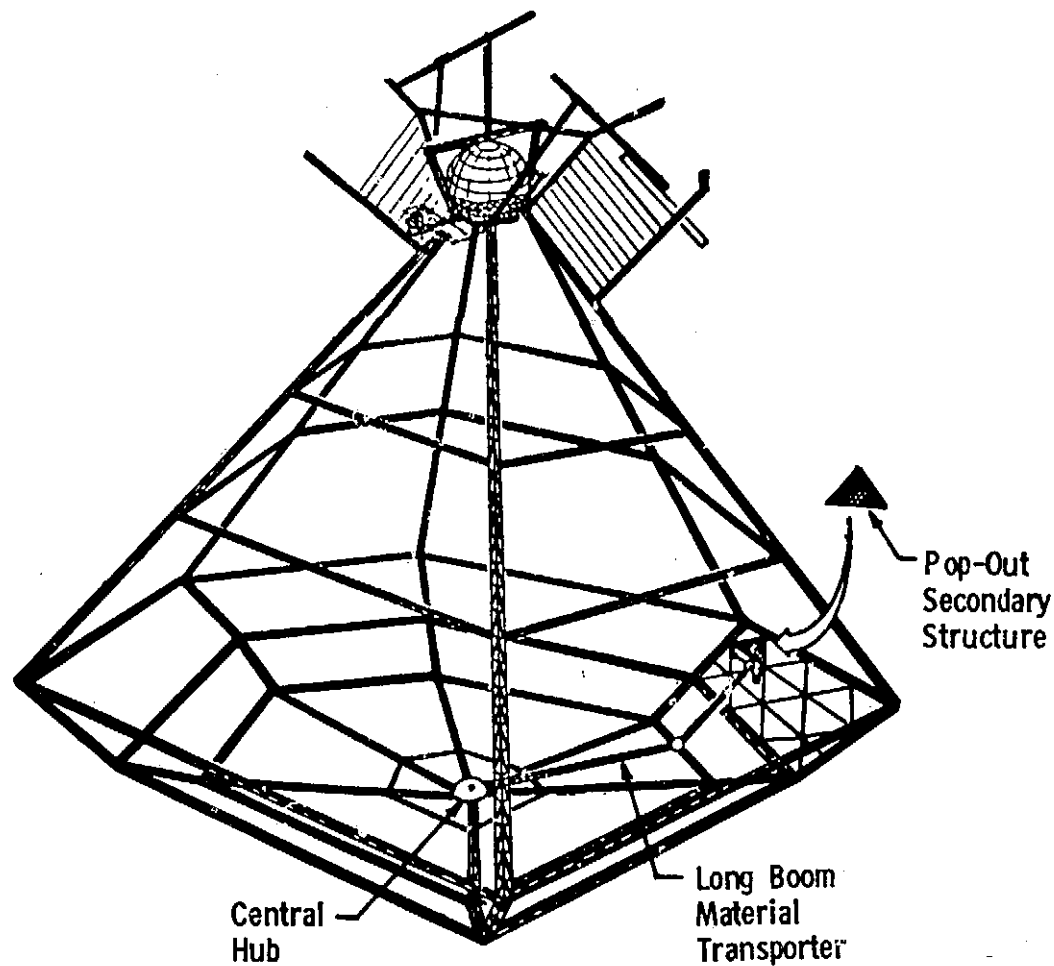
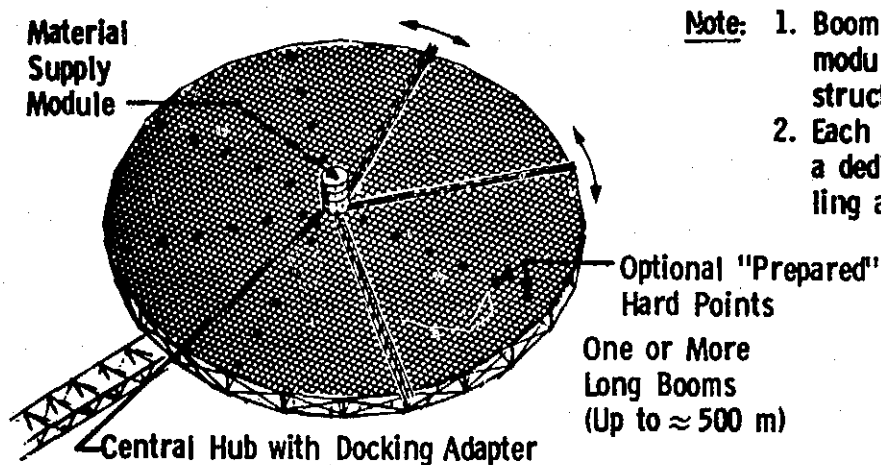


Figure 5.2.5-1 Thermal SPS Long Boom Applications

With respect to the MPTS construction scenario, many potential applications for the fixed boom were identified. This concept is shown in Figure 5.2.5-2 with the typical construction functions supported by the long boom.

5.2.5-3 Crew Participation - A long boom system requires, in general, two distinct types of crew involvement. The first type is one in which the crew is located at or near the worksite. In this case, direct vision is possible while the crew performs manipulative type operations.

The second type of crew involvement is where the crew is located at the central hub providing material resupply to the long boom. Some direct



- Note:**
1. Booms can be built up in modular fashion as construction radius progresses.
 2. Each application may require a dedicated mechanism traveling along the boom.

Frame Handling Fixture

- Holds basic 65x130 m frames prior to attaching one to another.

Cable Installed Mechanism

- Installs cables between hub and MPTS concentric rings.

Secondary Structure Installer

- Use two booms to "pull-apart" the secondary structure (≈ 130 m triangles).

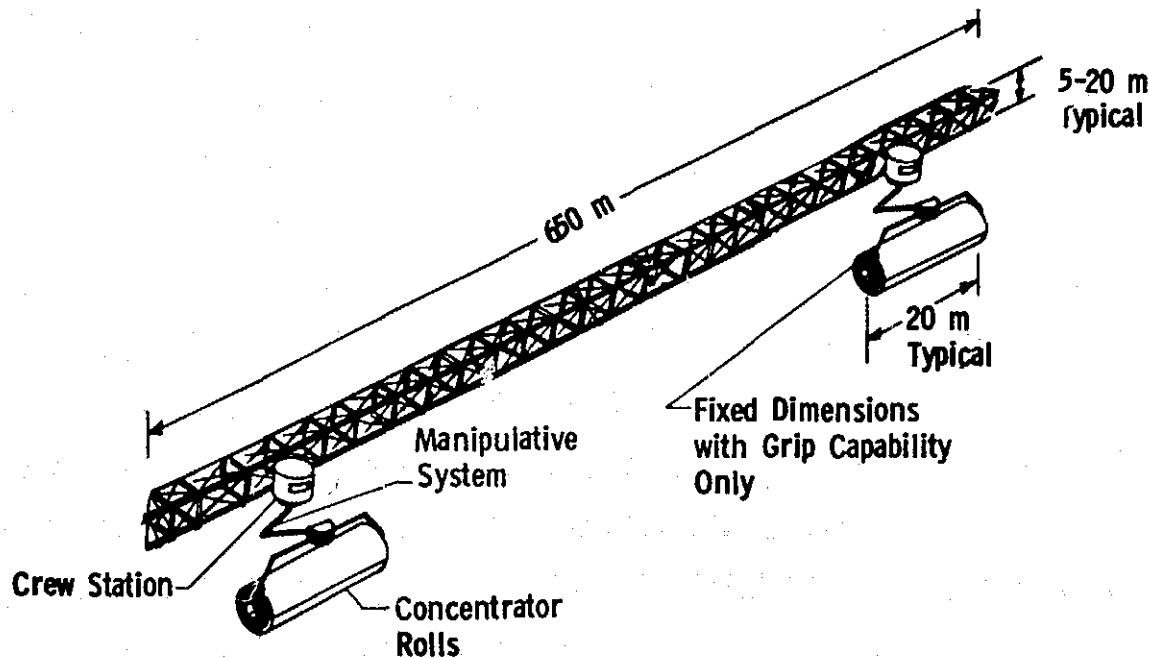
Subarray Transporter

- Feed/supply MPTS subarrays to the automated subarray installer.

Figure 5.2.5-2 Fixed Base Boom Applications to MPTS

vision of task activity would be available in the vicinity of the central hub but; for material transfer along the boom, some type of supervisory control would be implemented.

5.2.5.4 Concepts - Several concepts for the long boom were identified. The first, shown in Figure 5.2.5-3, provides supplies and support to automated construction equipment. As depicted, one or more crew stations, providing manipulative and handling capabilities, would be used to resupply the automated solar concentrator rolls to the concentrator installer. The key feature in this concept is the crew station, the manipulator system, and the material travel as a single unit.



•Similar to Cherry Picker but with Linear Travel

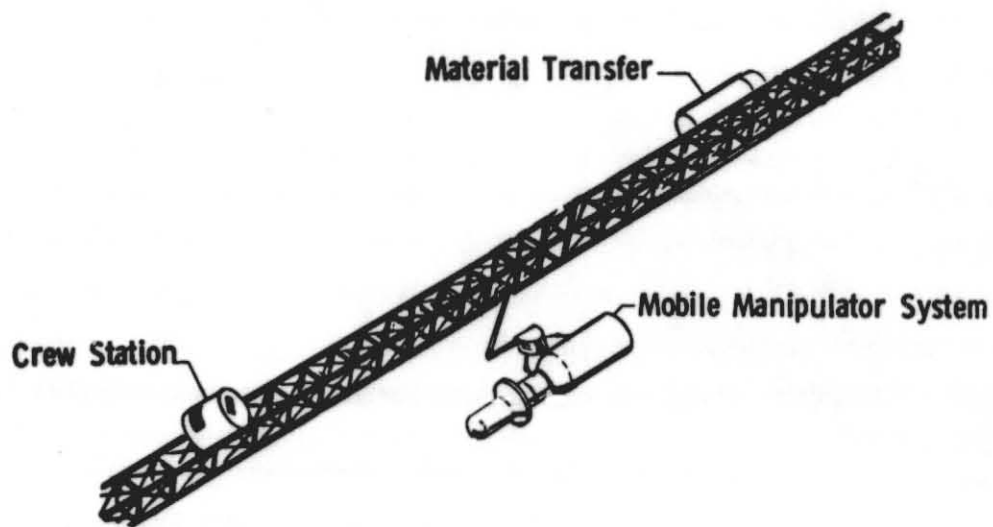
•Supplies One Concentrator Roll $\approx$ Every Hour

Figure 5.2.5-3 Fixed Base Boom - Integral Crew Station/Manipulator

A second concept providing more operational flexibility is illustrated in Figure 5.2.5-4. This concept incorporates independent transfer mechanisms for the crew station, the manipulative system, and the material. This concept enables the manipulator operator, in the crew station at the work site, to perform construction support tasks while a second operator, located at the supply base, would perform the functions as required for the material resupply.

In addition to enclosed crew station transfer, the long boom would also be used in support of crew transfer in an EVA mode, as shown in Figure 5.2.5-5.

Another concept or option for the boom is illustrated in Figure 5.2.5-6. This boom has pivoting capabilities at each end which enables the boom to move about on the structure. For example, when the boom pivots about end A,



- Independent Crew, Material, and Manipulative Translational Control
- Passing Capability Using Up to 4 Boom Sides

Figure 5.2.5-4 Fixed Base Boom - Independent Transfer

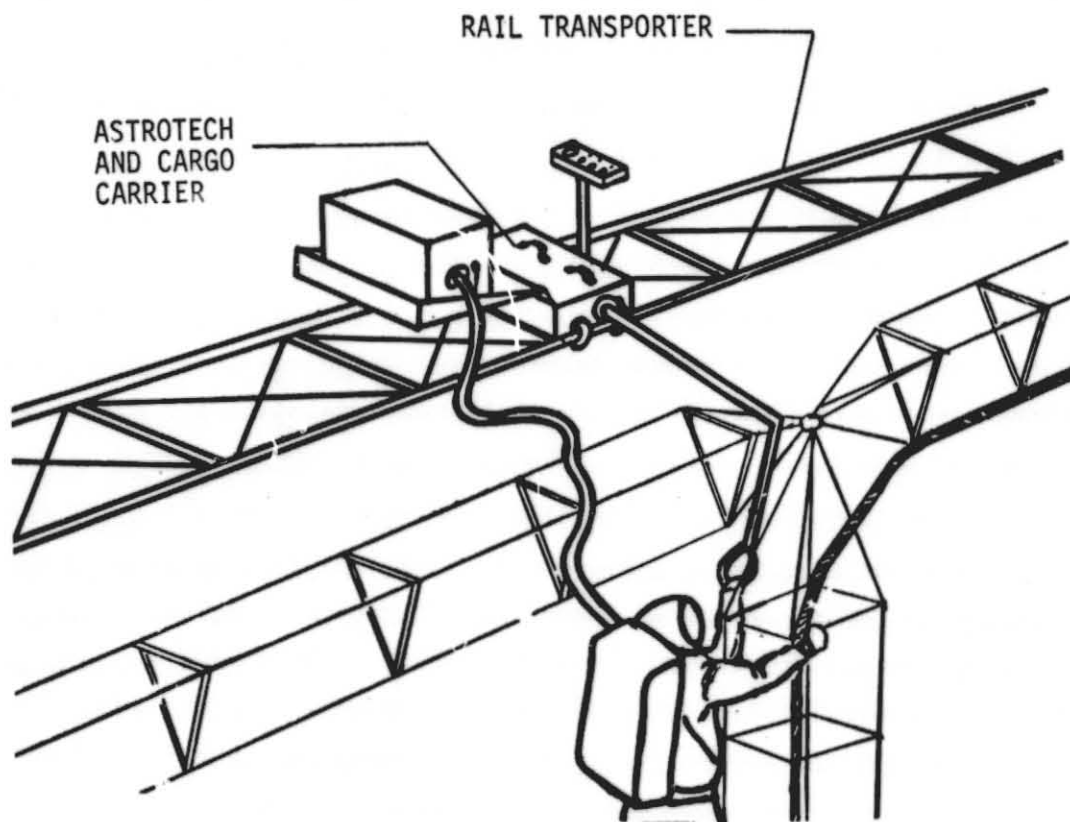


Figure 5.2.5-5 EVA/Boom Transporter Concept

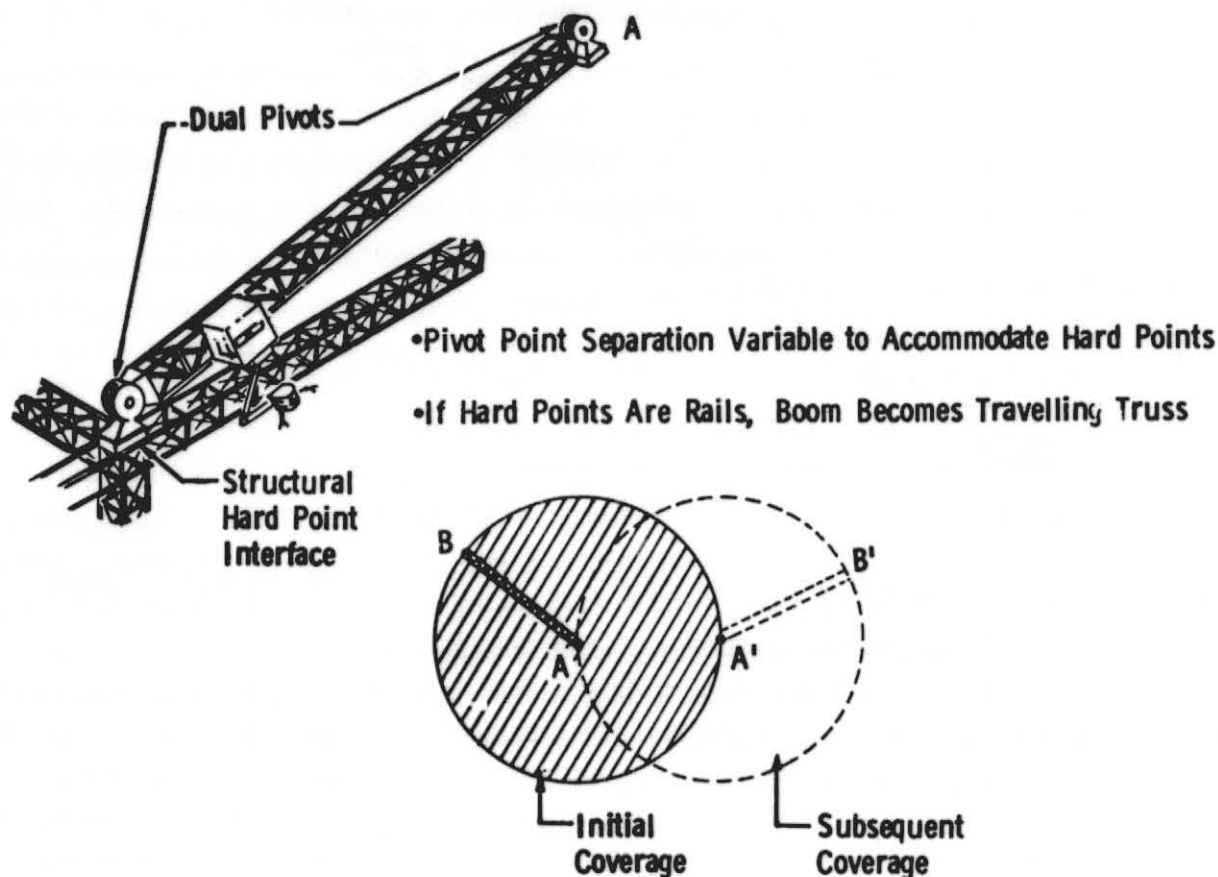


Figure 5.2.5-6 Mobile Boom Concept

a given circular area is covered as denoted by "initial coverage" in the figure. When end B is affixed to the structure at point B' and end A is released, the boom is now pivoted about point B' and the additional area denoted by "subsequent coverage" can be reached. In general, the pivot points (or boom/structure attachment mechanism) separation distance would be variable to accommodate the structural hard point interfaces which are not necessarily separated by identical distances. The similarity between this mobile boom concept and the mobile manipulator system shown in Section 5.2.1 is apparent.

It should be noted that rails might be incorporated in lieu of the hard points to provide continuous mobility. In this case, the mobile boom essentially evolves into a traveling truss configuration which has been proposed for application as construction equipment. One such example is shown in Figure 5.2.5-7 which is a Boeing approach for the installation of reflector and solar array surface on the truss type SPS.

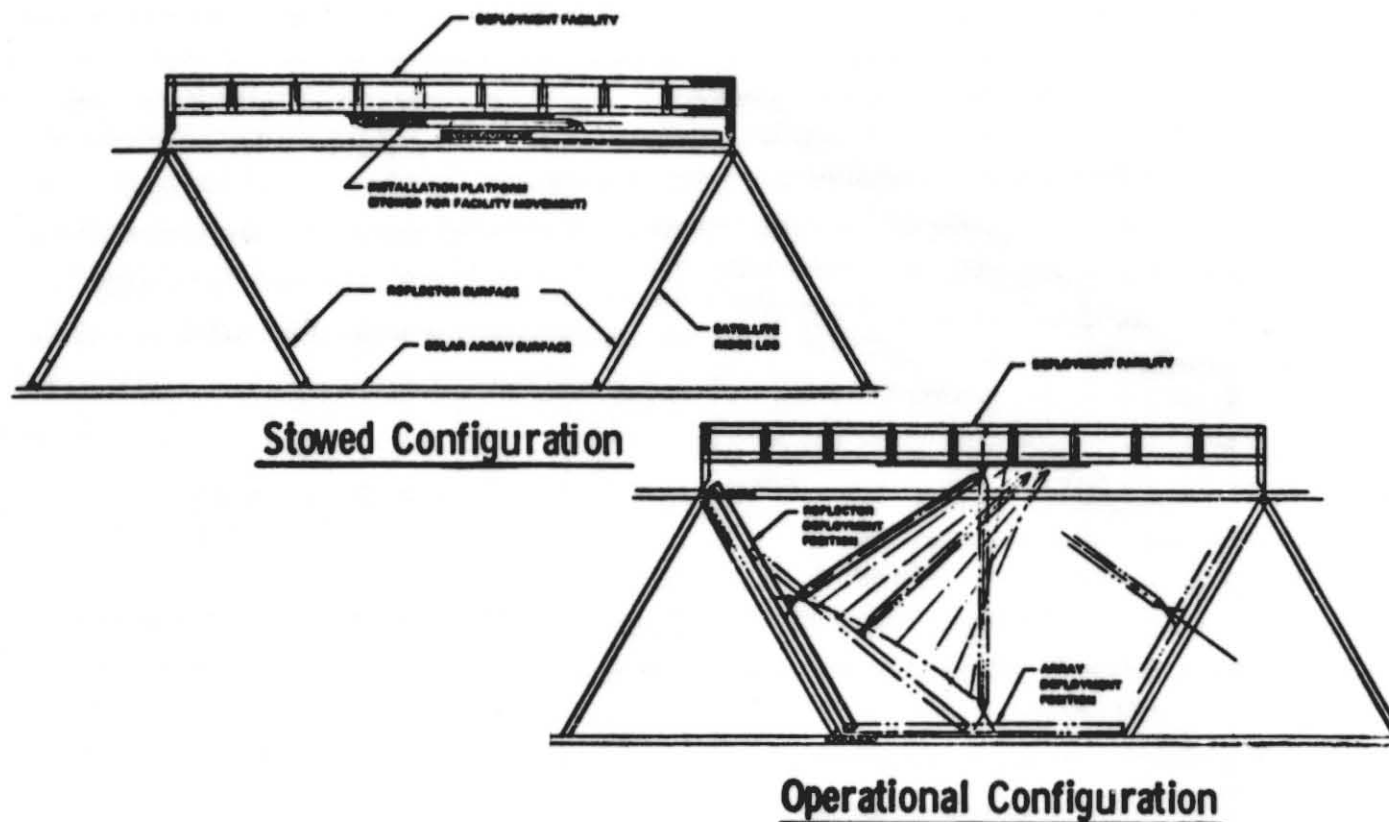


Figure 5.2.5-7 Boeing Truss Type Installation Concept

5.2.5.5 Subsystems

a. Boom Structure - The length of the boom is governed by the work area to be covered or the transport distance involved and may range up to 2 km; more typically, boom length is 100-500 m. The length theoretically has no limit if the boom is assembled on-orbit. However, as the length increases, additional requirements exist for support legs along its length (at interface hard points) to react the loads induced by the manipulator on the boom.

b. Long Boom Drive - Some long boom mobility drive techniques are illustrated in Figure 5.2.5-8. Technique (a) incorporates torque capability at the pivot point while in technique (b), the pivot has no active drive but uses the manipulative system on the boom to provide mobility. In the third case, the boom is attached to rails and the drive is continuous. This method is similar to the structural attached drive systems discussed in Section 5.2.5.8: Personnel/Material Transporter, Structure Attached.

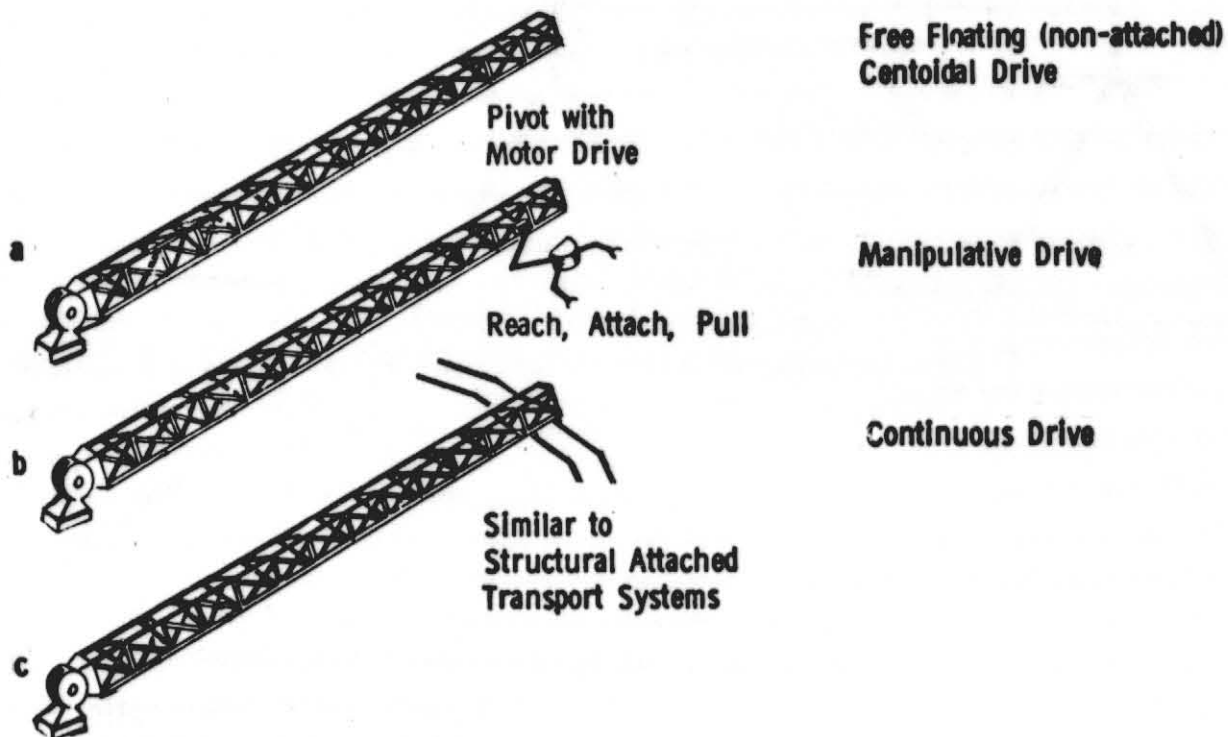


Figure 5.2.5-8 Long Boom Drive Techniques

c. Viewing and Control - For manipulative handling/installation direct viewing will be the primary mode of operational control with TV viewing a secondary mode. However, independent material transport phases will be controlled from the supply base via indirect viewing and possibly in a supervisory type control mode.

d. Power and Communications - The power and communication systems will be interfaced with the construction facility via hardwire at the structural hard points.

5.2.5.6 Environmental Factors - The major environmental factors affecting the long boom design are the hard vacuum and thermal impacts encountered over the extensive operational life requirements. The areas of greatest concern are the boom mobility and transport drive mechanisms.

5.2.5.7 Interface Considerations

5.2.5.7.1 Launch Vehicle - The long boom will be compatible with the launch vehicle as on-orbit assembly (or fabrication) is baselined.

5.2.5.7.2 Construction Facility - The long boom requires structural interfaces with the construction facility. The loads anticipated and the structural stiffness required must be defined.

5.2.5.8 Trade Studies - The long boom transport system requires trade studies in the following areas:

- a. Establish most feasible structural configuration--size and length based on specific applications;
- b. Determine operational loads, both longitudinal and radial;
- c. Establish number of, or distance between, interim supports as a function of boom loads/lengths;
- d. Analyze on-orbit assembly and disassembly; self-building vs segmented techniques;
- e. Investigate transport drive and guide systems; baseline required timelines to bound transport rates.

5.2.5.9 Development Plan - The future activities recommended as a result of the study and the restrictions assumed at this time have been summarized and shown in Figure 5.2.5-9. In general the long fixed base rotating boom has been identified as a necessary piece of OCSE in a number of the orbital construction tasks developed. The advantages identified warrant the consideration for development as operational OCSE in the 1995 time period. However, a review of the early large space structures demonstrations planned to date do not show an operational application. Therefore, early development is not as pressing, but an SRT effort should be started to take advantage of technologies being developed for Shuttle and SPS manipulators.

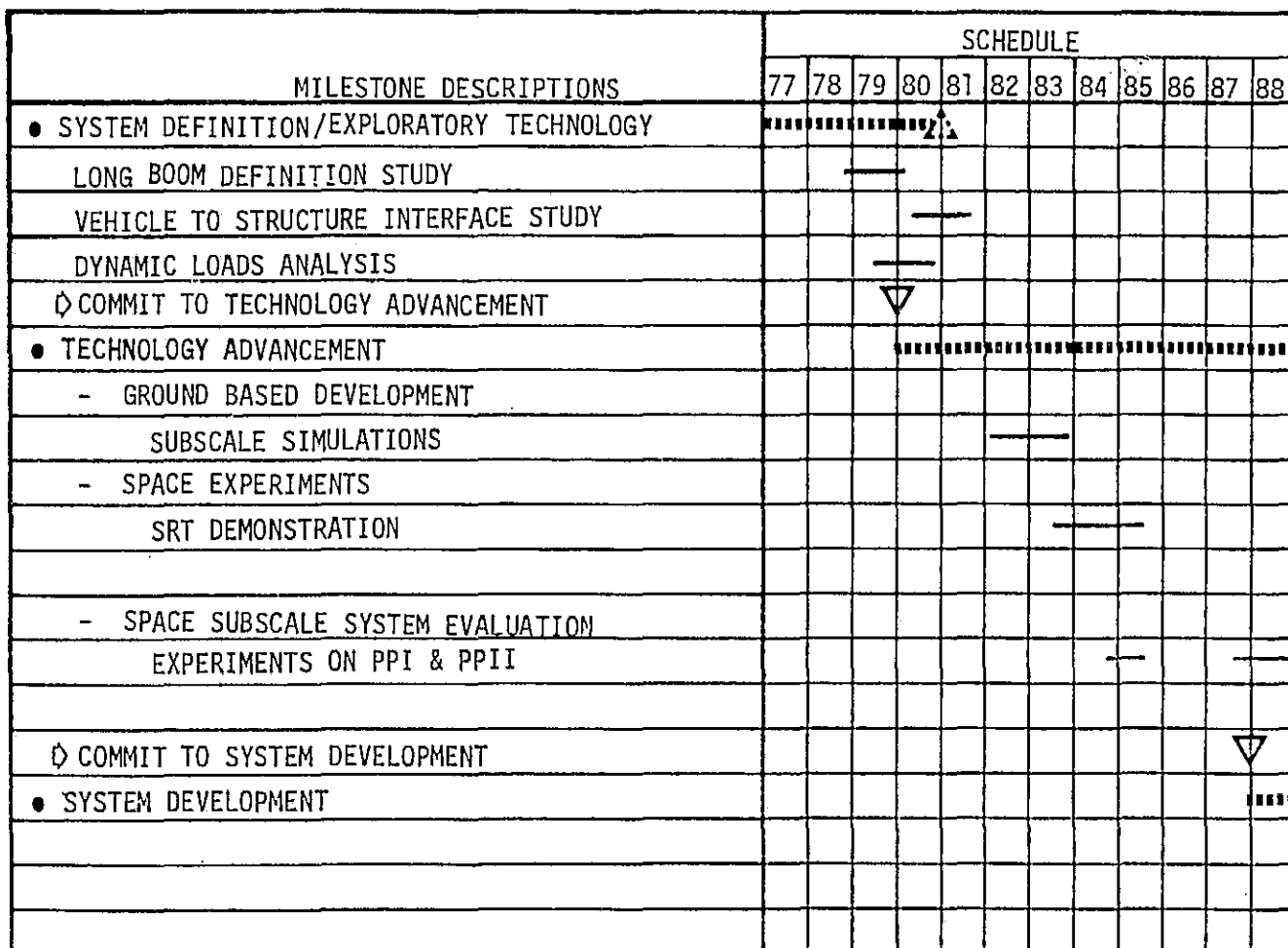


Figure 5.2.5-9 Fixed Base Long Boom Development Schedule

5.2.6 Maintenance Repair Module

5.2.6.1 Introduction - Solar Power Satellites planning to date has centered around the investigation of various designs, construction techniques, and operating methodologies to achieve low-cost solar power. Although many items contribute to cost effective program planning, the maintenance and/or repair question, with its many variables, embraces a majority of the design, operation and cost questions that must still be resolved before the full potential of the SPS can be achieved.

Considerable work has already been done relative to orbital maintenance for Shuttle experiment programs. A large number of maintenance studies have been performed for both NASA and DOD over the past few years. Many technology areas considered and resulting data from these studies seem relevant to the SPS maintenance question. One area of considerable importance was the emphasis that the later studies placed on grouping of alternative concepts on a common basis for economic comparison. The groupings or categories most often identified for comparison were expendable, ground-refurbishable, and on-orbit maintainable. All of the studies reviewed indicated the on-orbit maintainable mode to be the most cost effective when program ground rules identified such requirements as long life, large fleet sizes, low risk, etc. With this data as supporting rationale on-orbit maintenance was assumed for this study. It was also justified on the bases that it had the shortest time impact on construction scenarios in case of failures or contingency operations.

The level to which maintenance should be performed on-orbit was the next most pressing question. In general, it can range from a simple module remove/replace to the complete repair and checkout of the nonfunctioning module. While determining the level of equipment maintenance was not part of this study, the indication that maintenance would be required and that a maintenance facility would be feasible was made clear. Based on this line of reasoning, a maintenance/repair module (MRM) was assumed to be needed in support of the SPS construction and operation and as such could be considered as orbital construction support equipment (OCSE).

5.2.6.2 Functional Discussion - The maintenance/repair module (MRM) as envisioned is a centralized facility dedicated to performing scheduled servicing, scheduled and unscheduled maintenance, and component replacement tasks upon all OCSE. Maintenance upon construction equipment (CE) subsystems would

also be performed as required. The facility would have as its primary function the task of keeping all OCSE vehicles in operating condition. Failed components or subsystems would be removed and replaced so that the vehicle could be returned to service as quickly as possible. A secondary function of the MRM would be the inspection, failure analysis and possible repair and checkout of failed components. This would include small equipment capable of performing task such as clamping, drilling, welding, and possibly even some lathe operations.

5.2.6.2.1 General - In general, the MRM will provide a centralized facility for the repair and maintenance functions such as battery recharging, subsystems module replacement, component repair (on "time available" basis), scheduled/unscheduled servicing of vehicles. The facility would have an open hanger (unpressurized) section, docking ports, and a pressurized work (bench) area. Operations would be monitored/controlled from a pressurized control/display module within the facility.

5.2.6.2.2 Guidelines and Assumptions - Within the limitations of the study and based on related ongoing studies, the following guidelines and assumptions are presented:

a. The MRM has been assumed here to house all maintenance/servicing systems and, as a result, is the logical place at which shift changes will occur.

b. If small, independent servicing stations are required at scattered locations, these units will be of unique (to the construction base philosophy) design.

c. Intravehicular Activities (IVA) capabilities will be provided in a general shop configuration format.

d. IVA for this study will be defined as those activities which take place within pressurized areas of habitable facilities.

e. All life support provisions will be provided by the crew habitability facility.

f. The MRM will have its own contingency and emergency pressurization system.

g. It was assumed that the MRM would be located near the EVA module to utilize the EVA capability in the unpressurized repair bay.

5.2.6.2.3 Applications - The specific module configuration concept presented here seems to have application to other SPS requirements, for example, this module could be used as a general facility to all equipment used on SPS construction; a space station/construction base logistics facility might include this type of module for maintenance/repair of CE, OCSE, orbit transfer vehicles, etc. The unit could also be used as either a fixed base vehicle or a free flying vehicle to perform maintenance and repair during SPS operation. In addition this module could be used in conjunction with a fabrication facility where there might be a sharing of unique equipment.

5.2.6.2.4 Trade Studies - Many areas related to the potential design of a maintenance/repair module for OCSE require more detailed investigation. The actual complement of vehicles and equipment (both number and function) to be utilized in construction and construction support will determine the overall size of the MRM. The optimum method of moving the vehicles within the MRM must minimize delays due to traffic and provide for efficient space utilization. The designs of the hoists, cranes or gantries must be further defined in functional terms so that operating techniques can be established. The actual level of maintenance to be performed in the MRM (assumed in this discussion to be only down to the component replacement level) should be identified so that work flows and commodity resupply schedules can be estimated. The control and monitoring system could be based on the system utilized in the beam builders but would be more sophisticated due to the use of manipulators and other general purpose handlers in the MRM, and to the probability of simultaneous operation of several unrelated maintenance subsystems.

5.2.6.3 Crew Participation - The MRM as envisioned would play a major role in the area of crew participation. Due to the required interaction between man and machine in performing maintenance tasks the human factors considerations will be very critical in the interim design of the MRM. Man/machine compatibility in the design and location of equipment, restraints, controls, displays, lighting and workspace must be optimum if the MRM crew is to effectively accomplish the maintenance objectives.

5.2.6.4 Concepts - Different MRM configurations were proposed which varied widely as far as structure size, functional tasks, shift size, internal pressure, etc. A review of these configurations matched with some of the more reasonable support requirements identified in part I resulted in the selection for further development of the concept shown in Figure 5.2.6-1. Some of the major options identified were such questions as; should the MRM be attached to the cluster or have free flight capability, should it operate in LEO or LEO and GEO and should it be sized to perform maintenance on small transport vehicles or also OTVS. Many of these types of questions cannot be resolved at this time, however, assumptions were made which resulted in proposing a feasible concept defined in the following paragraph, capable of identifying potentially soft technology areas that may be encountered.

Three major classes of OCSE would be maintained by the proposed facility. All surface transport vehicles, OCSE free-flyers, and EVA modules (e.g., ECWSs) would be accommodated by the systems provided in the maintenance/repair module. In addition, servicing and repair of orbital transfer vehicles (OTVs) could be accomplished in the MRM, and component replacement of CE subsystems could be performed.

The MRM would contain three main work areas, each of which is dedicated to a particular type of maintenance task. An unpressurized "garage" section would perform day-to-day (or shift-to-shift) servicing such as refueling/recharging, and effector changeout, and checkout of major subsystems. Parking places for vehicles (surface transporters and free flyers) would be provided where servicing could be accomplished using remotely controlled umbilicals, connectors and manipulators.

A second unpressurized bay is provided for scheduled and unscheduled maintenance. Failed components/subsystems would be removed using remotely controlled manipulators, and replacement parts would be installed. The vehicle would then either return to the work site or be moved to the garage bay for normal servicing. Vehicle changeout, such as converting a personnel surface transporter into a cargo transporter, would also be accomplished in this repair bay (see Figure 5.2.6-2). All MRM operations would be coordinated from the third main work area, which would contain a pressurized control room. Equipment such as cranes, gantries (for transporting vehicles within the MRM), manipulators and service panels would be operated and monitored from this control room.

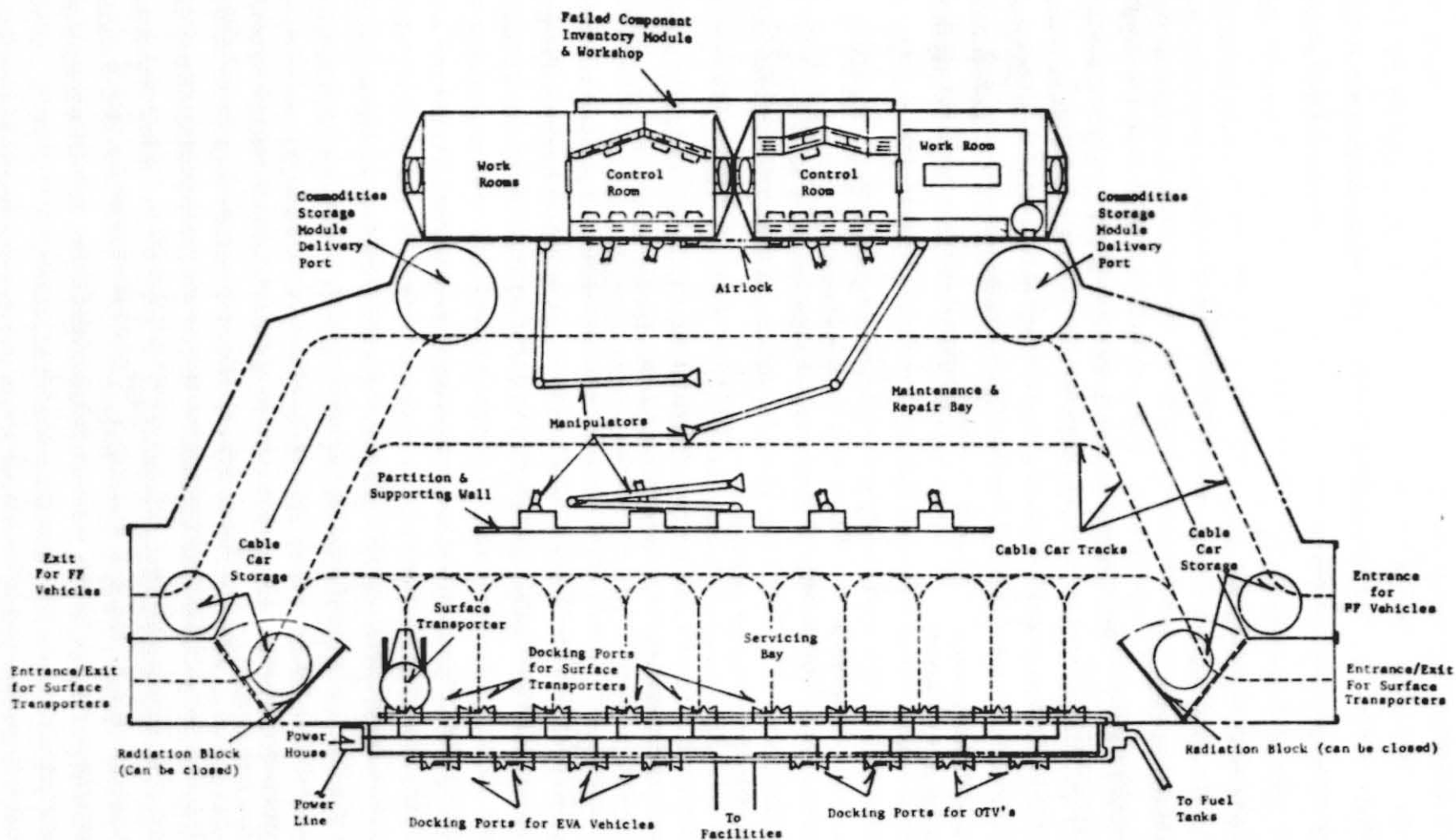


Figure 5.2.6-1 Maintenance/Repair Module Concept

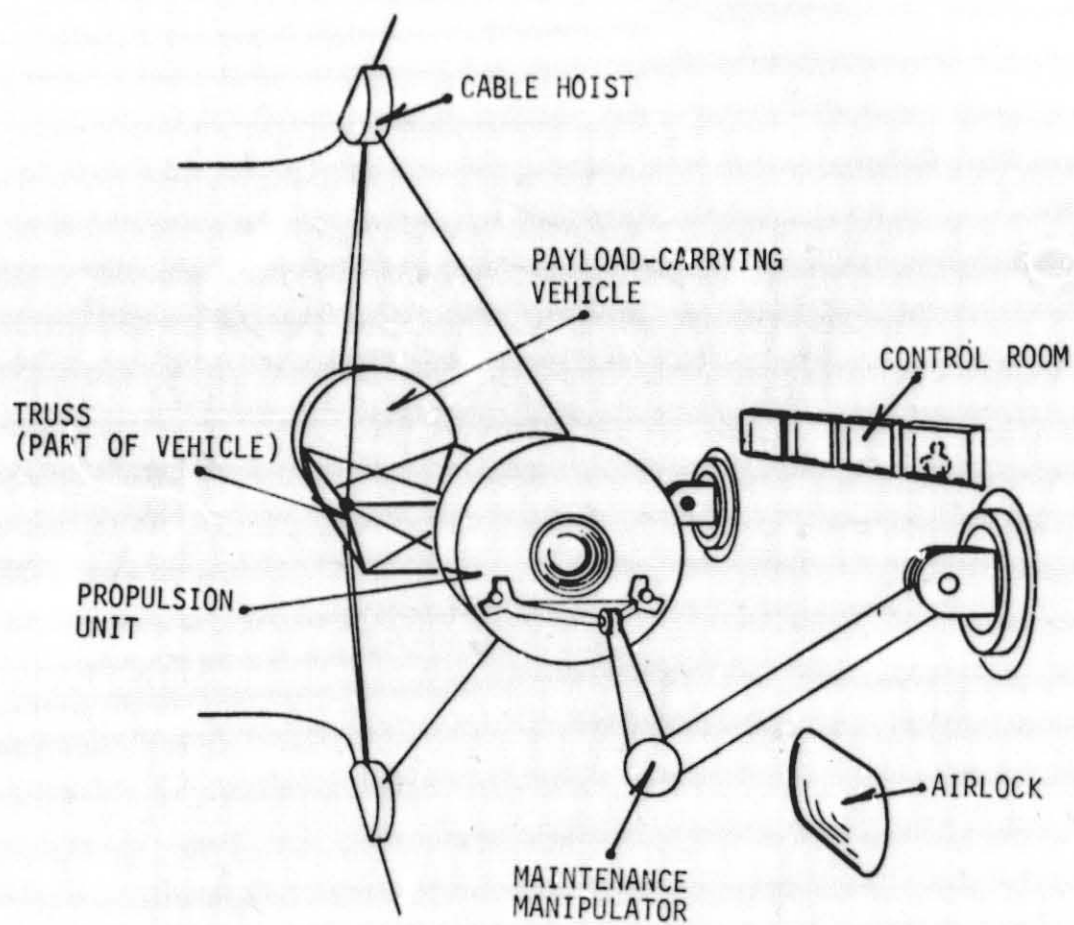


Figure 5.2.6-2 Personnel to Cargo Transporter Conversion

Additional pressurized sections adjacent to the control area would contain work shops and benches (connected to the open bays via airlocks), for hands-on component repair. Although it is anticipated that most failed components would either be returned to a separate facility (perhaps the manufacturing facility in LEO) for repair or simply discarded (materials could be reclaimed for recycling in the MF), some repair work could be accomplished in the MRM. An inventory of failed components would be maintained, and personnel could attempt repairs on a "time available" or schedule need basis.

Also included in the MRM would be the equivalent of a tow truck, which would retrieve immobilized transporters or major subsystems from the construction site and return them to the MRM for repair. This tow truck would be a surface transport vehicle reconfigured as required, and could also be used to transport replacement components for on-site maintenance activities. Only those maintenance jobs which cannot be completed at the construction site in a reasonable amount of time will be done in the MRM.

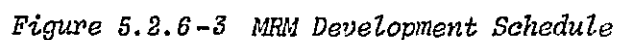
5.2.6.5 Subsystems - TBD

5.2.6.6 Environmental Factors - The major environmental factor effecting the MRM design is radiation impacts. While there is very little problem with radiation in LEO, operation in GEO could present a major problem. An ongoing NASA study -- ECWS, NAS9-15290, is looking into this problem area. Data from this study and from other related studies should be available for future design considerations.

5.2.6.7 Interface Considerations - In general, the interfaces identified with this vehicle would be similar to those required for other modules which make up the construction base cluster. Typical samples of projected interfaces are as follows:

- MRM/Habitability Facility
- MRM/Logistics Facility
- MRM/Transport Vehicles
- MRM/Commodity Resupply Module

Feasibility of this concept could impose a human factor impact upon access requirements for both the EVA and IVA remove and repair mode on OCSE and CE components.



5.2.7 Commodities Storage

5.2.7.1 Introduction - The concept of reusable orbital spacecraft introduces many new requirements for designers of systems and supporting equipment. The traffic routes are many and diverse for moving men, material, components, equipment, large assemblies, and facilities during the construction process. Consequently, there is a definite need for providing supply depots, refueling stations, etc. Because of the materials or fuel types, the locations and procedures used to provide this storage and supply function must be accomplished with minimum risk to personnel and equipment involved. Also, evaluation of different options in terms of time, complexity, lighting, safety, cost, etc. need be considered.

5.2.7.2 Functional Discussion - The commodities storage facility (CSF) as required will provide a storage capability for commodities such as fuel, water, propellant, coolant, gasses, nuclear materials, etc. necessary to operate many of the different transport vehicles. The unit envisioned to provide this is a centralized facility which serves as the supply depot for the OCSE. Although the eventual SPS construction philosophy may dictate the use of a large warehouse for all SPS commodities or the use of smaller distributed warehouses of specific nature, this discussion is limited to the storage and supply requirements inherent to the OCSE. It is recognized that the CSF described here may well be incorporated (functionally or physically) into a larger SPS logistics facility.

5.2.7.2.1 General - In general, the CSF will provide a single facility located away from or attached to the basic SPS construction base cluster. Some of the past studies which could be helpful in this area include: Development of Space Maintenance Concepts for the Reusable Nuclear Shuttle, NAS8-27297, April 1972; Transfer of Fluid Between Space Vehicles; and Resupply/Repair of Solid or Hybrid Attitude Propulsion, NAS8-29196.

This is one effort in which very little work could be done at this time since configurations are highly dependent on SPS program groundrules. However, some concepts were looked at as shown in the following paragraphs.

5.2.7.2.2 Guidelines and Assumptions - Within the limitations of the study and based on related studies the following guidelines and assumptions are presented:

a. The CSF has been assumed here to house all maintenance, storage and transfer servicing systems required in support of all potentially dangerous resupply commodities.

b. If small, independent commodity storage and supply stations are required at scattered locations, these units will be of unique (to the construction base philosophy) design.

c. The CSF will also house spare parts, subsystem replacement modules and other materials required in support of the Maintenance/Repair Module for OCSE.

d. Activities in and requirements of the CSF will be coordinated with (or assimilated into) equivalent SPS support facilities.

e. Accommodation limits within the CSF will be determined by the overall SPS and OCSE construction and maintenance philosophy.

5.2.7.2.3 Application - The prime objective of the commodities storage facility is the storage and transfer of fuel and fuel tanks required by orbital transport vehicles. As such the associated requirements are considered to be rather dedicated in nature. The requirement for crew safety is one of the most limiting design parameters. This has a great impact on location and the role of crew participation. From all initial indications the commodities-storage facility would be a dedicated facility for fluids and hardware which have a personnel safety implication. However, this shouldn't limit the potential of making use of spare areas available on the CSF for such items as batteries, spare parts, tool kits, replacement end effectors, subsystem modules (communications, GN&C, thruster pads, etc), etc. This facility could also serve as a storage area for idle OCSE vehicles or equipment.

Some of the potential areas significant to the design of the CSF which should be studied in more detail include optimization of storage arrangement, supply retrieval techniques and inventory control. The items to be stored in the CSF range from the very small (e.g., 0.1 m^3 electronics package) to the relatively large (e.g., transport vehicle personnel module, 5 meter diameter x 15 meters long). All items must be stored in such a way that they are accessible for retrieval. Once the overall maintenance philosophy has been defined, reliability analyses and fleet size will determine the types and quantities of items which need to be stored. Efficient utilization of space will, of course, minimize the storage volume required.

The actual technique used to retrieve items and deliver them to the MRM must be detailed. Although an automated or remotely controlled cart traveling over a rail system has been assumed here, other concepts are also feasible. The mechanisms required to handle the commodities can be as simple as a fork lift or as complex as a multiple degree of freedom manipulator. It is anticipated, however, that the entire system will be made as simple as possible.

Inventory control methods used in the CSF will be dependent upon its overall capacity (number of items stored at any time) and upon its relationship to the SPS logistics facility. Subsequent definition of construction base logistics will allow determination of such requirements for the CSF.

5.2.7.3 Crew Participation - A top level cut in this area indicates scheduled operations associated with the CSF and man should be conducted on a manned remote basis. Thus, the prime design consideration would be one of man/machine compatibility in design and layout of displays, controls, lighting, etc. to provide the remote operator an effective means to accomplish the mission objectives.

5.2.7.4 Concepts - Two very simple concept approaches were investigated and partially developed for each of the major commodity storage and transfer functions. This was done to aid in determining an overall CSF concept that seems to satisfy the functional requirements for commodity storage and transfer. The two concept approaches were:

- Cluster Attached/Manned CSF
- Cluster Detached/Unmanned CSF

The Cluster Attached/Manned CSF concept provides a wide range of storage and supply functions applicable to other base modules.

Since the storage and supply requirements for OCSE are also based upon the servicing/maintenance functions, a primary functional interface of the CSF could be with the maintenance and repair module. The efficiency of the complete system would be enhanced if the two modules are close together or even physically connected. Figure 5.2.7-1 shows one possible arrangement of the two modules, after assembly in orbit.

The CSF is configured in this concept to accept supply deliveries, store items such that they are easily accessible, retrieve items as required using an automated or remotely controlled cart, and deliver the item to the MRM.

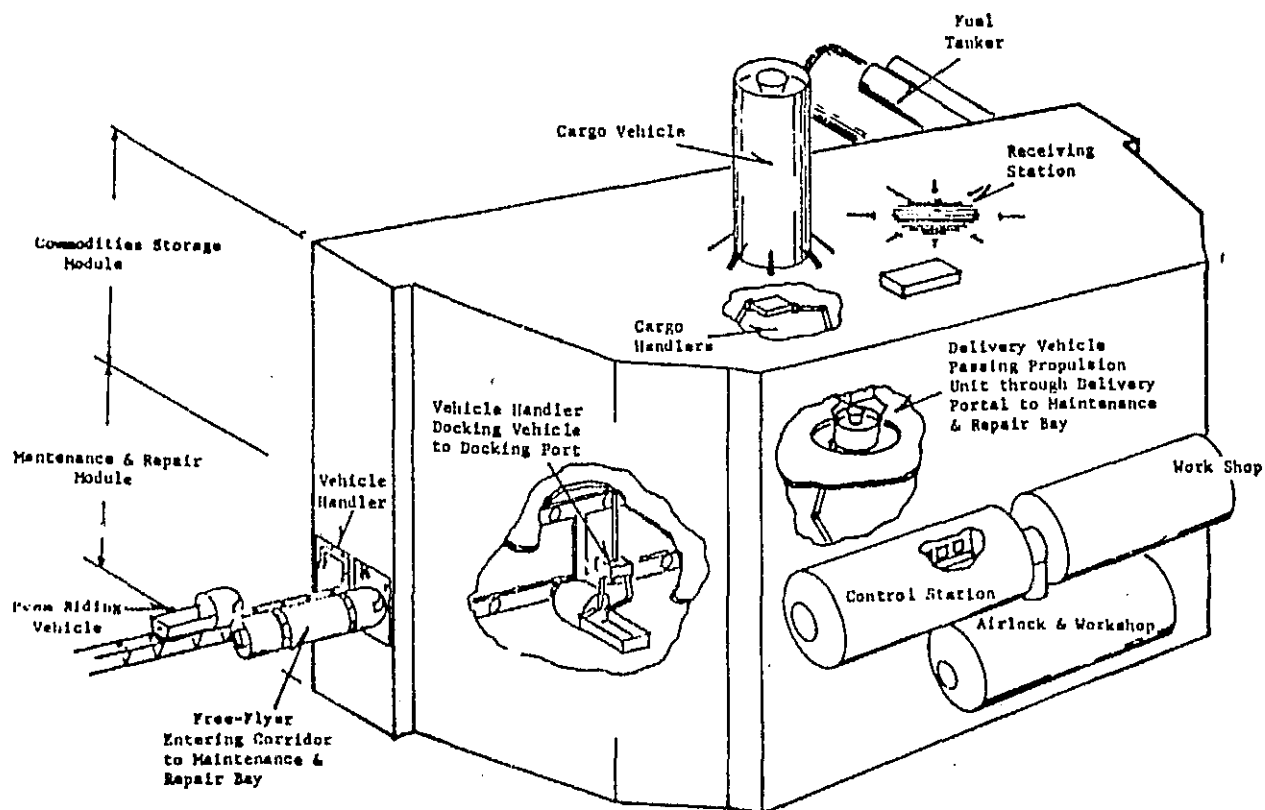


Figure 5.2.7-1 Manned CSF/MRM Configuration Concept

Figure 5.2.7-2 shows a typical floor plan for the CSF. A small pressurized enclosure serves as the control and monitoring station for the module; the main storage bays are unpressurized.

The second concept looked at was the cluster detached unmanned commodities storage facility. This concept utilizes equipment that is partly autonomous in that it is a stable unmanned platform. The assembly and operations that are nonautonomous are performed by remote operators back at the Integration Management Facility (IMF) or in a contingency mode by EVA personnel.

The assembly activities that are remotely controlled by man make use of teleoperator system (TOS) in either the free flying or fixed base types operating on the platform. Due to the versatility of teleoperators, the quantity of support equipment needed for the CSF is minimized over the quantity of autonomous equipment that would be required.

A typical scenario would include the launching of specific structure sections and assembly equipment from earth on HLLVs to a designated orbit

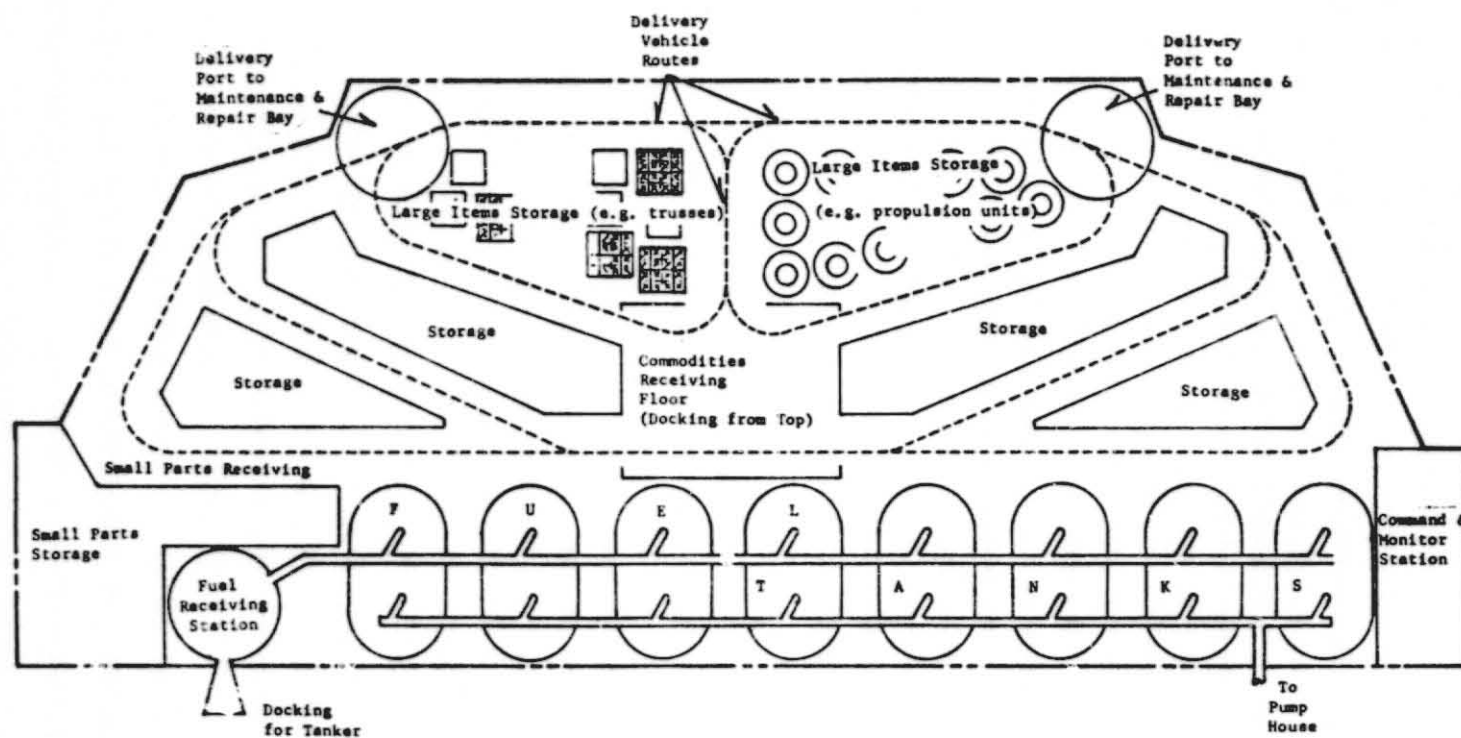


Figure 5.2.7-2 CSF/MRM Typical Floor Plan

location. Once the desired orbit is achieved the HLLV will either perform a startup phase or maneuver and dock with an existing CSF. After docking has been confirmed, transfer of commodities from the HLLV to the CSF will take place. The method of transfer could be done by umbilical connection and fluid transfer, or by module removal and replacement (fluid tanks or high pressure spheres). The HLLV would then undock and return to earth.

An option to this sequence would have the HLLV stationkeep at a safe distance while unmanned free flying teleoperators maneuver out to the HLLV dock with the HLLV payload and transport it back to the CSF. Figure 5.2.7-3 presents an artist's concept by Westinghouse which gives a typical picture of what a commodity storage tank farm might look like.

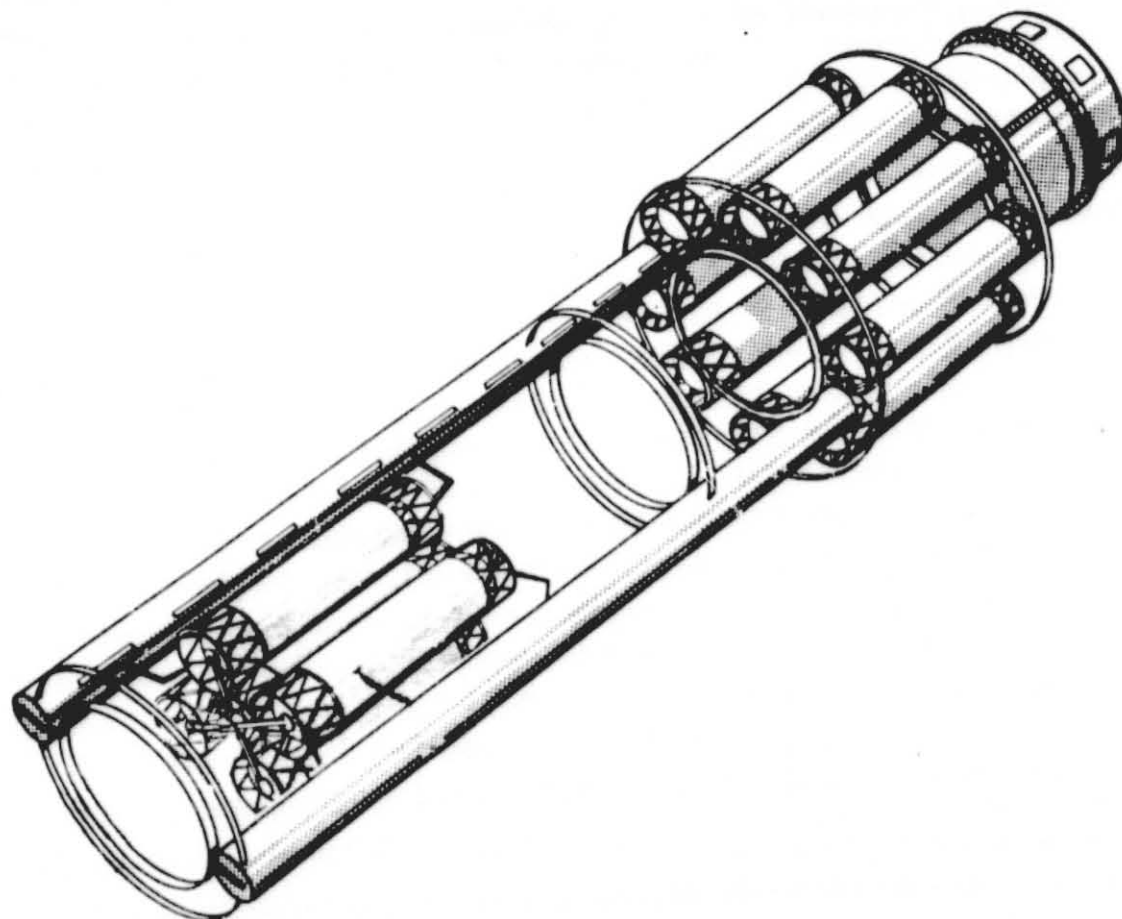


Figure 5.2.7-3 Remote Controlled CSF Tank Farm Concept

5.2.7.5 Subsystems - TBD

5.2.7.6 Environmental Factors - The major environmental factors effecting the CSF design are radiation and thermal impacts. While there is very little problem with radiation in LEO, operation in GEO could present a major problem. An ongoing NASA study--ECWS, NAS9-15290, is looking into this problem area. Data from this study and from other related studies should be available for future design considerations.

5.2.7.7 Interface Considerations - In general the interfaces identified with this vehicle would be similar to those required for other modules which make up the construction base cluster. Typical samples of projected interfaces are as follows:

CSF/Habitability Facility

CSF/Logistics Facility

CSF/Transport Vehicles

MRM/Commodities Storage Facility

CSF/HLLV and OTV

Material Transfer Interface Connectors

5.2.7.8 Development Plan - The future activities recommended as a result of the conclusions reached in this preliminary evaluation are summarized below and on Figure 5.2.7-4. The initial effort projected is the development of ground rules and economic benefits of the overall commodities storage and resupply picture. Research and development should also be continued on remote maneuverable teleoperators. Also, SRT should be initiated on materials, to be used on both the CSF and the OCSE, which will be used on hardware exposed to the combination of the normal space environment combined with radiation environments of materials stored.

The test planning, scheduling and facilities utilized are greatly dependent on the development and scheduling of other base modules. For example maneuvering and docking requirements are very similar to many of the other base module requirements. The emphasis in this area is in the system definition/exploratory technology because conclusions resulting from this phase can drastically change the later planning.

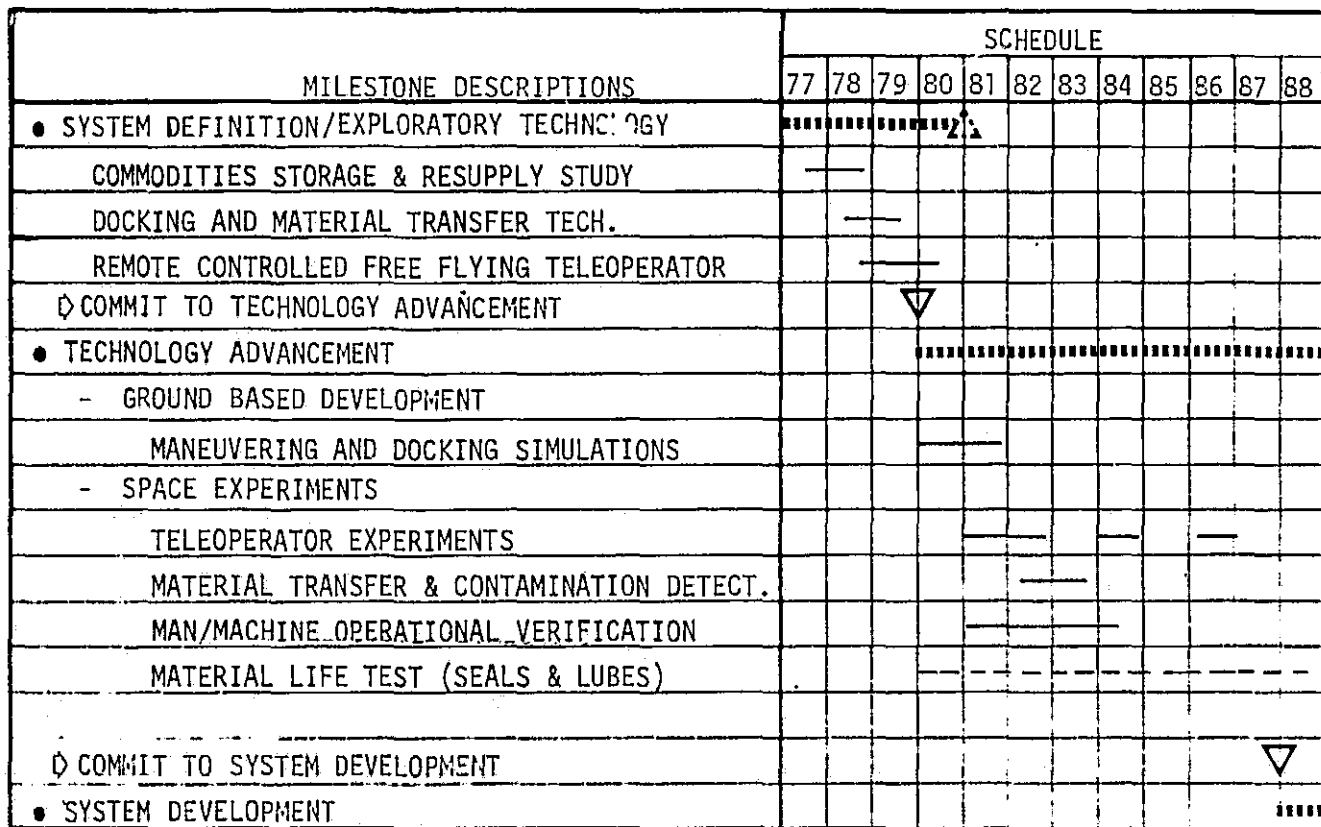


Figure 5.2.7-4 CSF Development Schedule

5.2.8 Personnel/Material Transporter, Structure Attached

5.2.8.1 Introduction - Any type of large space structure will require a significant amount of personnel and material transportation both during initial construction and for long-term maintenance. These transporters should also be capable of assisting in the construction and maintenance tasks by carrying man-operated manipulators and other tools to and between work sites. Some of the assembly tasks would be assisting in beam joint attachment, installing solar concentrators and panels, cable attachments, etc. During the maintenance phase replacement of concentrators and panels, repairing broken structure or cables, inspections, etc will be a logical set of activities in which personnel, utilizing transporters, will be engaged. Much of the travel required during SPS construction and maintenance can be accomplished on existing structure (beams or cables).

5.2.8.2 Operational Discussion - This section will be devoted to the general description of a transporter, the design requirements, and applications of the vehicle; in addition, the trade studies that need to be accomplished prior to selecting a preliminary design concept will be identified.

5.2.8.2.1 General - From previous preliminary studies of various structure attached transporters, it has been concluded that the vehicle should traverse the basic SPS structure (beam or cable) without requiring specially dedicated cables or rails. The transporter would be self-propelled on the structure by electric motor driven wheels powered from an internal power pack or bus bars on the structure. This vehicle would transport personnel, materials, and equipment, and would double as a tool to assist in the space structure assembly and maintenance after construction.

5.2.8.2.2 Guidelines and Assumptions - The following list of guidelines and assumptions are in fact preliminary design criteria for the next phase of the transporter program and are flexible enough to permit modification, deletion or addition as the design is formulated.

- a) Transport a maximum of 10 personnel, if used as a crew transporter.
- b) Transport the materials necessary to assist in the initial SPS construction such as solar concentrators, solar panels, structure joints, and tools, when used as a material transporter.

- c) Transport all the materials and tools necessary for maintenance of the space structure for replacement of equipment, repairs of basic structure and cables, etc.
- d) Contain teleoperator station (controls and displays) and manipulators to effect construction and maintenance (vehicle shall be directly controlled by an operator).
- e) Derive power from the SPS by bus bars or rechargeable power packs.
- f) Design of motive devices to interface directly on the basic structure with a minimum of extra tracks, guides, etc.
- g) Provide for inspection of all parts of the SPS construction base by direct viewing or remote camera coverage.
- h) Provide capability for access to all areas of the SPS for maintenance tasks.

5.2.8.2.3 Applications - Figure 5.2.8-1 summarizes the functional interfaces which apply to structure-attached transporters. Such considerations are significant to the development of OCSE. Transportation of personnel or material, for example, on or within existing beam structure is affected not only by the beam design, but also by the joints between beams (see Figure 5.2.8-2). Intra-beam transfer is limited by the dimensions of the beam triangular cross-section (typically 2.5 to 20 meters). Transfer over a beam is influenced by the beam material, load constraints and the existence of travel restricting joints. Considerations important to the use of existing cables for surface transportation are summarized in Table 5.2.8-1.

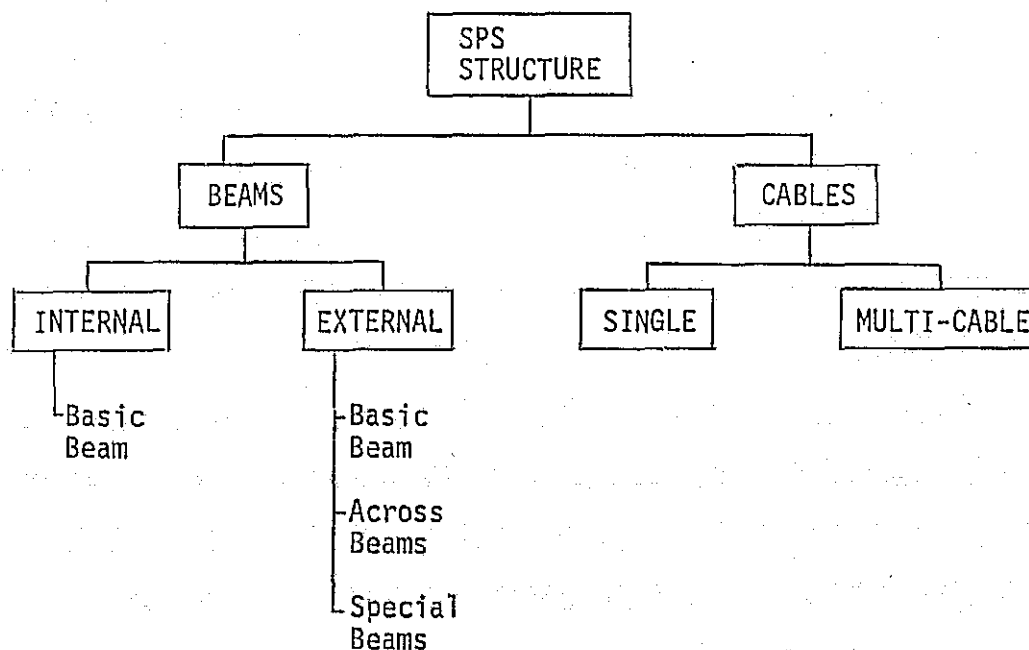


Figure 5.2.8-1 Structural Interface Considerations

Table 5.2.8-1 Cable Transport Considerations

OPTION	ADVANTAGES	DISADVANTAGES
Single Cable	• Can use existing (passive) SPS cables	• Orientation about cable difficult to maintain • Module interchange between cables requires additional support equipment
Dual Cable	• Module stability increased by 2-pt. attachment • Allows transport of more material	• Travel restricted by requirement for two parallel cables • Module interchange between cable systems requires additional support equipment • May require modified or dedicated (second) cable
Spider Concept	• Provides greater transport flexibility (three-dimensional or planar) • Allows module to get close to work area without actual contact	• Requires dedicated cable transport system • Not efficient for transporting large amounts of material

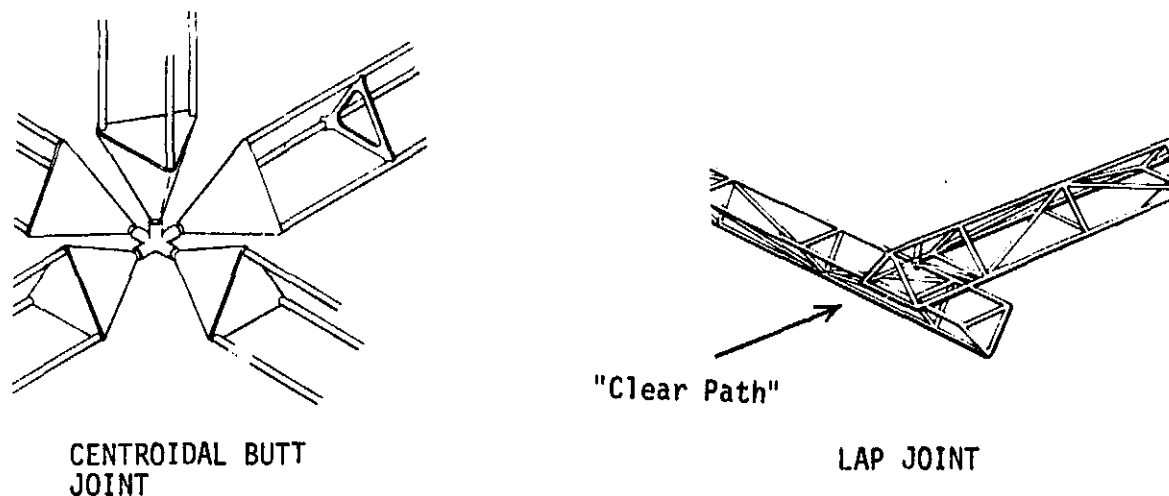


Figure 5.2.8-2 Beam Transportation vs Joint Design Considerations

The column/cable SPS might present a unique requirement for cable-attached transporters. The nonpower carrying cables on the C/C-SPS are to be approximately five centimeter diameter Kevlar. The amount of exposed cable ranges from 360° to 60° of the circumference of the cable. Two types of cable joiners will most likely be used: the first will be a standard clamp-type joiner; the second, a pulley arrangement, like that used at the prime-subprime cable junction (see Figure 5.2.8-3). Both hand-held and rideable cable transporters can be envisioned.

One type of hand-held, cable-traversing vehicle would be placed on each cable comprising each joint before the joiner is put on. An astronaut starting at one joint would grasp a vehicle which he would use to take him to an adjacent joint at which he would grasp another vehicle, repeating the procedure until he arrived at the desired location (see Figure 5.2.8-4). Some disadvantages related to this type of vehicle are: the supplies carried are limited to what the astronaut can control with one hand; batteries need to be carried either by the astronaut or changed periodically; stops are required at each joint. The advantages to such a vehicle are its simplicity and controllability, and the ease of installation.

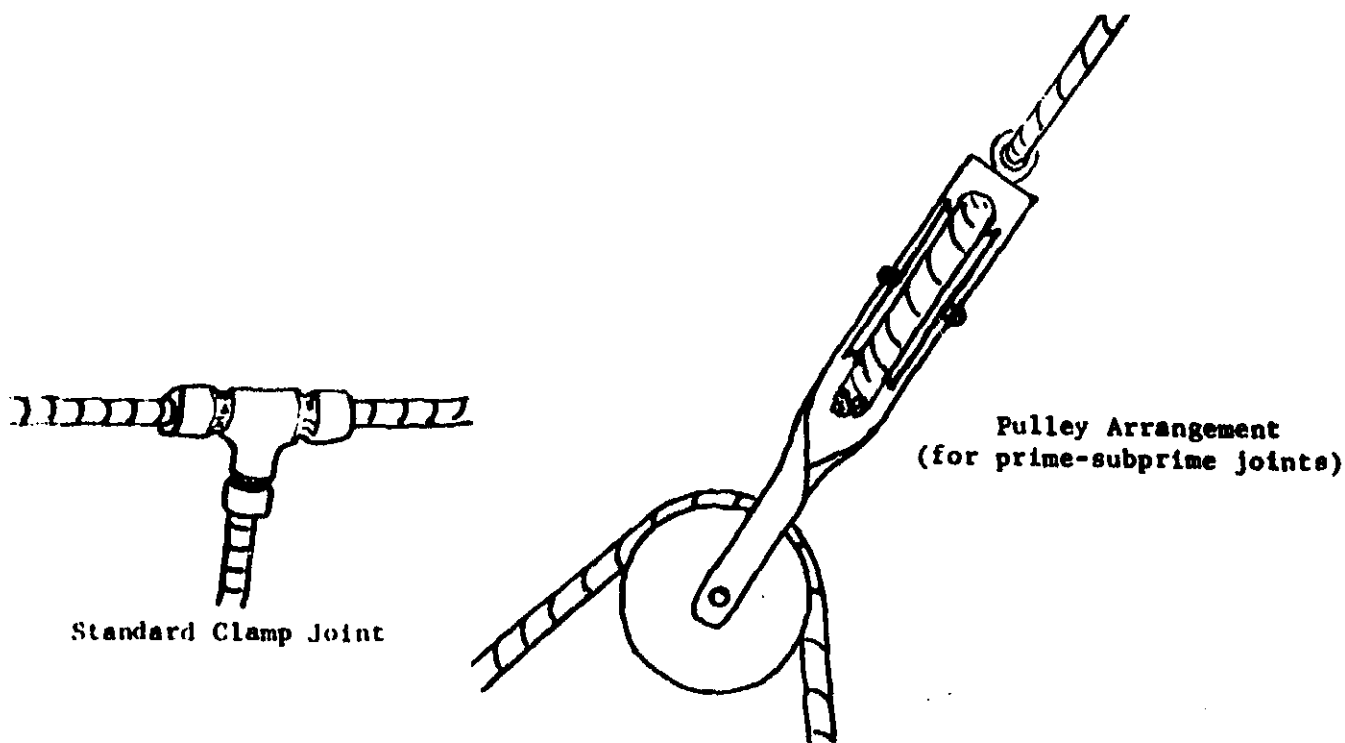


Figure 5.2.8-3 Cable Joints

A second type of hand-held cable-traversing vehicle would be that type that could change cables. This vehicle would "sit" on top of the cable and grip the underside of the cable with a series of paired wheels, each pair of which acts independently from the other pairs. For a smooth transition between joined cables, wires would be strung to bypass the joints (see Figure 5.2.8-5). This type of vehicle could be carried as a regular part of the astronaut's tool kit and clamped onto any convenient cable. This vehicle would be faster than the non-cable-changing vehicle and would be cheaper to use. If bypasses were not employed, the astronaut would have to stop at each joint to change cables. Another disadvantage is its limited carrying capacity.

The second type of cable-traversing vehicle is the rideable type. A non-cable-changing, rideable vehicle would not be efficient, since it would

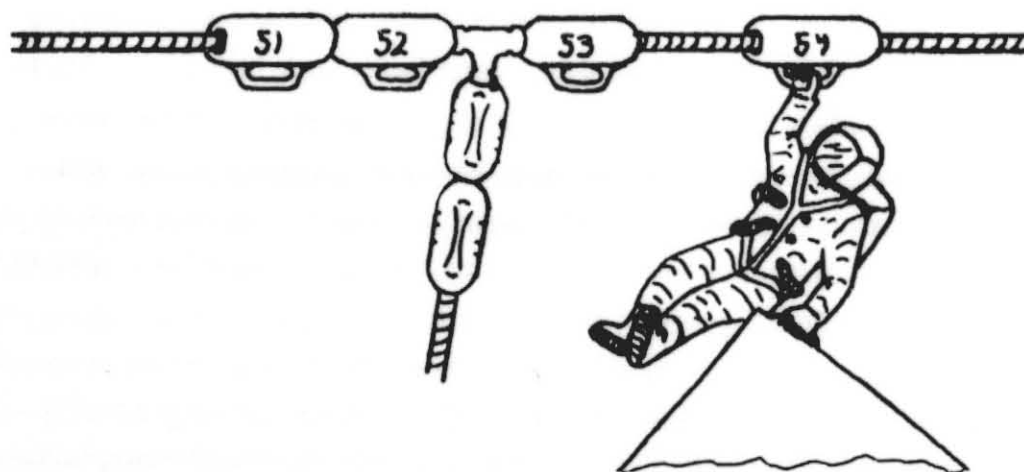


Figure 5.2.8-4 Hand-held Cable Traversing Vehicle

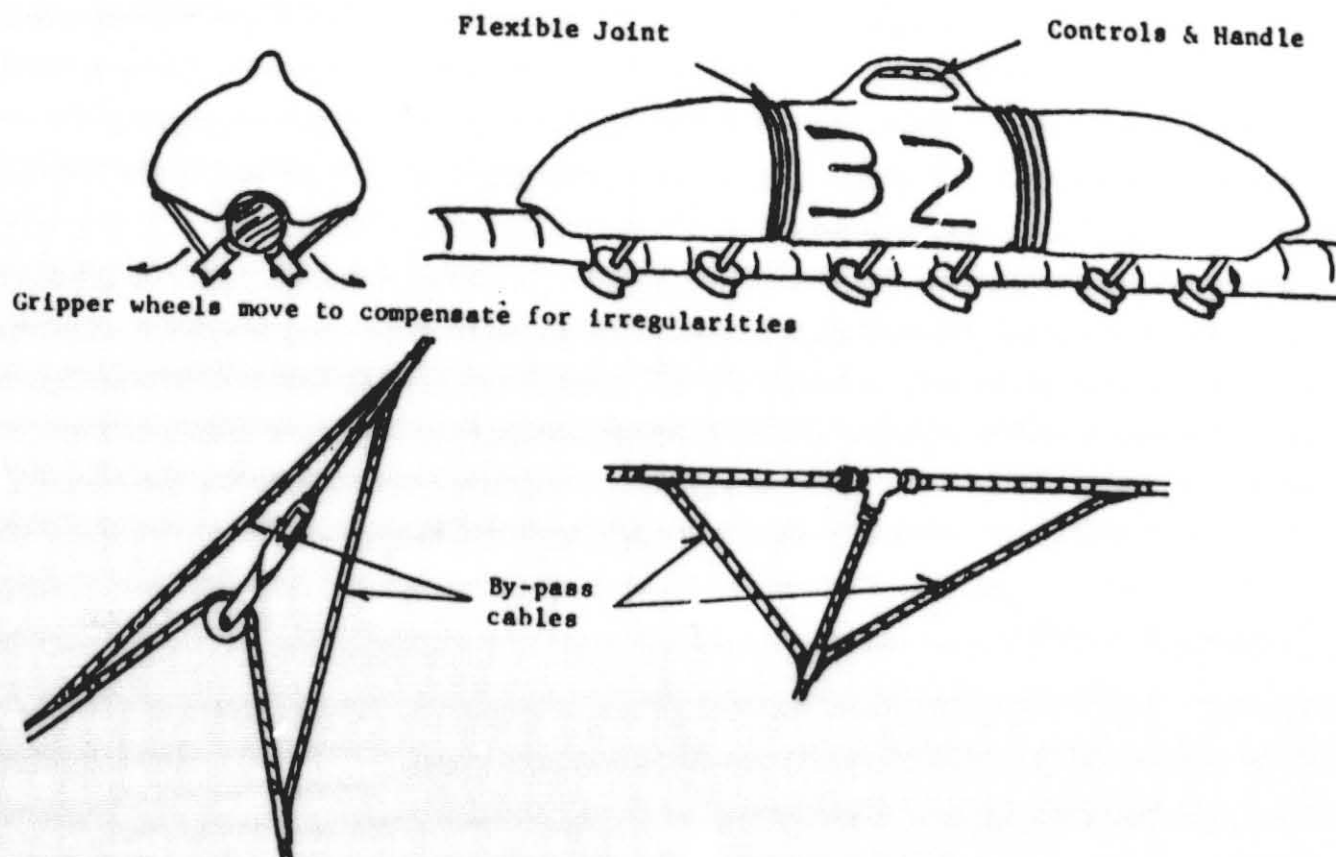


Figure 5.2.8-5 Joint Bypasses for Cable Traversing

probably transport packages of enough mass to preclude their being switched to a different vehicle at each joint. A rideable, cable-changing vehicle (Figure 5.2.8-6) would necessarily employ the same types of gripper wheel and joint bypass systems as the hand-held, cable-changing vehicle (on a larger scale). This vehicle would be able to carry massive loads, would be very easy to control, should be relatively fast and could be coupled with a free-flying system. What might be considered disadvantages are that bypasses must be installed, and the vehicle would be complex.

A second general type of vehicle which would be used on the C/C-SPS is the "spider" vehicle. In general a spider vehicle anchors some type of appendages on the existing cables, using these points as foot holds from which to move.

A spider vehicle could be constructed which would use manipulator-type arms to walk across the surface of the C/C-SPS, using the subprime cables as footholds in tandem. This vehicle could lower itself to within a few meters of the solar panel surface where it could repair the surface with manipulator arms and/or cherry-picker-type vehicles. To cover the entire surface of a 1-km square described by four subprime cables the spider would need four legs, each consisting of two 700-meter booms. The motion of this vehicle would be similar to that of a walking spider.



Figure 5.2.8-6 Rideable Cable-Changing Vehicle

A second type of spider vehicle would replace the legs of the first type with cables whose ends are fastened to devices similar to hand-held, cable-changing vehicles (Figure 5.2.8-7). This vehicle would "fly" to the prime-subprime cable joint above the section to be repaired, attach the cable-traveling devices to the subprime cables, and, by regulating the cable lengths and the velocity of the cable-traveling devices, descend to the desired area. This vehicle would also use manipulators and/or cherry-picker type vehicles to repair the surface. This type of vehicle reduces the chance for contamination to the solar panels by using cable drive systems starting at the prime-subprime cable joints (high above the solar array surface) and lowering itself to the surface. Space could be conserved by constructing the manipulator arms and cherry-picker booms from collapsible beams (i.e., Astromasts^(R)).

Applications involving beam-attached transporters are potentially much more extensive, because the anticipated SPS design (even the C/C-SPS) will include structural beams both as part of the construction base and the SPS itself. Such transporters would be most adaptable for use on the triangular beam concept of large space structures where a specific size of basic triangle is used for all the main beams, cross beams and diagonal beams. A spiral construction would be less adaptable, but for most maintenance and inspection tasks traveling around the spiral beams would still be required. The column/cable construction is the least desirable for a beam attached transporter and additional studies will be required to assess the impact of added dedicated transporter beams against the complexities of a cable attached vehicle. In addition to transporting personnel and material this beam-attached device will have great utilization to assist construction by installing solar panels, solar concentrators, bus bars, cables, wiring, etc. Personnel in the transporter would have direct viewing of most tasks, as opposed to remote video coverage by unmanned assembly vehicles. The same advantages exist for the manned transporter for both SPS inspection, and the repair and maintenance of damaged or malfunctioning components.

Since it is desirable that existing beams be utilized by the transporter, the specific design of the beams should be such that they can accommodate an attached transporter. Figure 5.2.8-8 shows possible modifications to proposed beam designs which would make them compatible with beam traversing transportation

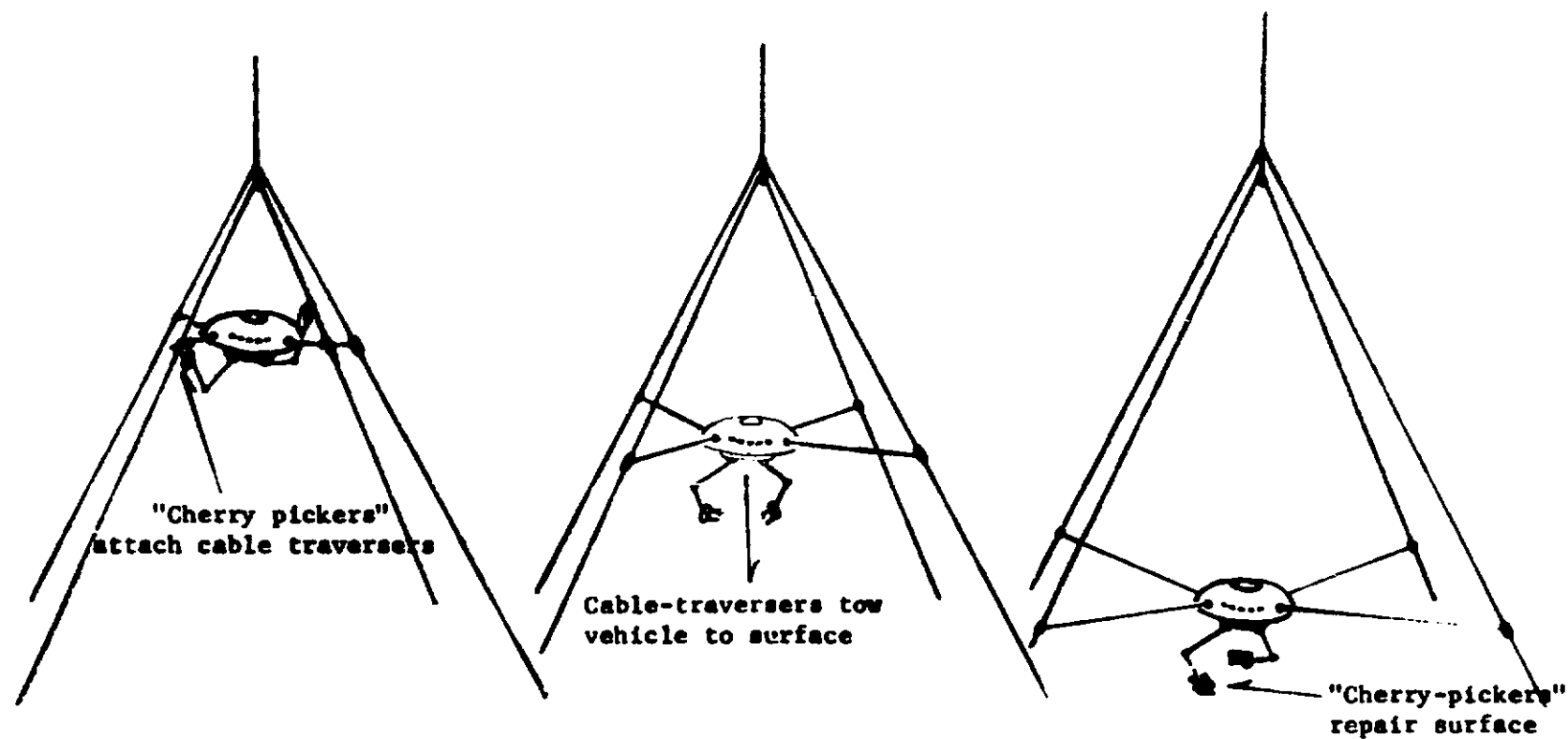


Figure 5.2.8-7 Cable-Guided Spider

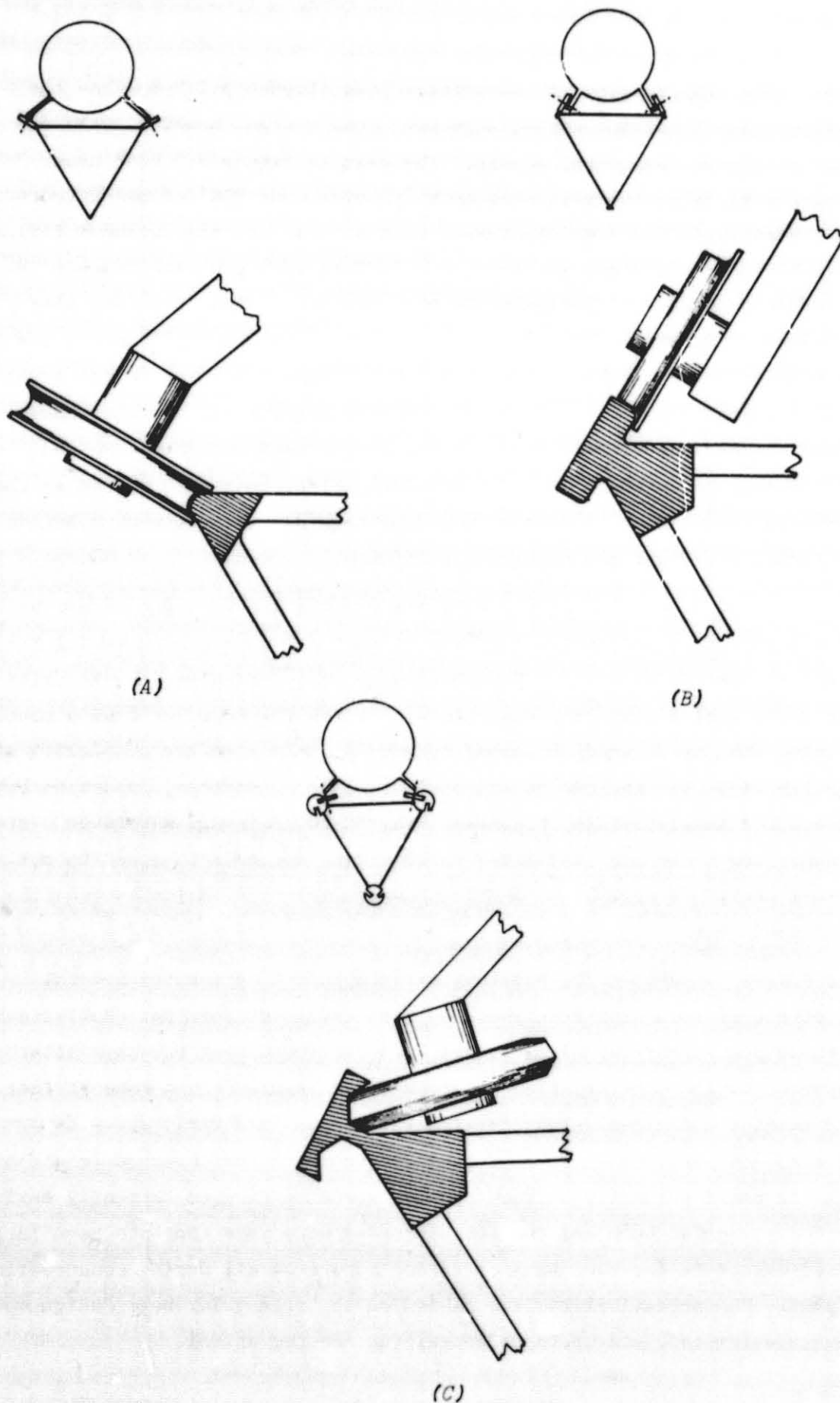


Figure 5.2.8-8 Possible Beam Designs to Accommodate Transporters

systems. The system using the unmodified beam (Figure 5.2.8-8A) has the desirable characteristics of not impacting beam design; however, only one vehicle at a time can travel a beam. The beam in Figure 5.2.8-8B uses point connections of its cross-braces to provide over 270° of unobstructed beam. Up to three vehicles can travel this beam at one time without influencing each other. The beam in Figure 5.2.8-8C is equipped with troughs in which the wheels of the transport vehicles may ride. This beam may also accommodate up to three vehicles at one time without them influencing each other. It would appear that a beam able to accommodate three vehicles would be more desirable than a beam only able to accommodate one vehicle; however, the best method must be determined by the impact each method has on the required strength of the beam. The use of an electromagnetic system at the beam/vehicle attachment interface should be considered since such a system might reduce beam load requirements.

5.2.8.3 Crew Participation - All structure-attached transporters will require direct crew activities for vehicle control, personnel/material transfer and subsystem monitoring. Depending upon the particular vehicle utilized, the operator will perform his tasks in either the EVA mode, or from a pressurized cabin. The trade studies needed to address this item are complexity of crew activities, sophistication and cost of vehicle controls, impact on basic structure for runways, joint bypasses, etc. Crew training, automated systems, redundancy are among the many elements requiring an in-depth study to optimize the final design as well as to provide comparative information between the various candidates.

5.2.8.4 Concepts - The previous paragraphs have presented several applications of candidate transporters, both cable attached and beam attached. From these preliminary studies, it has been concluded that the beam attached transporter is the more practical approach, and is the design concept that should receive additional study, design refinements and early space demonstrations. The rationale for selecting the beam attached over cable attached systems is based primarily on the types of space structures currently envisioned. Both the triangular beam and the spiral spider structure concepts have large areas of structure for the transporter to transverse all during construction or repair. The accessibility from cables on the triangular beam design would be severely limited, and would be nonexistent on the spiral.

It must be reiterated that to provide an optimum transporter system, the basic SPS structure design must incorporate the features required to support the transporter. At the same time studies must be conducted for the transporter motive power. Table 5.2.8-2 lists some advantages and disadvantages of four possible concepts of beam attached transporters, and the following paragraphs describe each concept in more detail. Variations of these ideas and additional approaches will undoubtedly be conceived and added to the trade studies. Each of the suggested ideas, beam traveler with manipulators for legs, the two designs requiring joint bypasses and the free flyer, travel on the basic beam structure, but each have unique features that will affect the design of the beams. Each of the four transporters fulfill the important criteria of paragraph 5.2.8.2.2; travel the basic structure; use structure electrical power; transport astronauts, materials and tools and have access to most areas of the structure for inspection and maintenance.

- a) Beam Traveler - No matter what type of propulsion or grapnel is used, a problem which any beam traveling device will have is changing from one beam to another. One possible way to change from one beam to another is shown in Figure 5.2.8-9. This vehicle is attached to its beam gripping and propulsion system through four manipulators. To change beams this vehicle reaches out and grips the desired beam with its front manipulators and then pulls itself over the joint. This is shown in the four plates.

Another way to avoid joints when changing beams is to use a joint bypass system. The bypass system would be constructed and fitted around the joint so as to provide a smooth transition from one beam to another for the chosen gripping and propulsion system. The beam to which a vehicle is directed is dependent on the side of the beam on which the vehicle is traveling.

- b) Static Rail Changer - To use a bypass system as described above, the beam traversing vehicle must be able to switch to the side of the beam which will take it in the desired direction. Two methods of doing this have been suggested. The first method is shown in Figure 5.2.8-10. Before approaching a joint having bypasses, this vehicle stops to change sides (if necessary). The vehicle uses a

Table 5.2.8-2 Structure Attached Transporter Considerations

OPTION	ADVANTAGES	DISADVANTAGES
Beam Traveler	● Does not require special structure at joints to bypass. ● Manipulator legs could double as work tools.	● Requires four manipulators. ● Would have to stop to change direction or continue on at joints.
Static Rail Changer	● Has positive grip on bypass beams. ● Manipulators could double as work tools.	● Requires special bypasses at joints. ● Must stop at joints to change direction. ● Requires two manipulators.
Dynamic Rail Changer	● Only requires two small arms at joint bypasses. ● Does not need to stop at bypasses.	● Requires special bypasses at joints. ● Needs manipulators for work tools.
Combination Free Flyer/Rail Vehicle	● Eliminates need for docking and receiving stations. ● Minimizes distance vehicle must travel on structure. ● Eliminates bypasses at joints. ● Could carry larger loads.	● Requires special "runway" structures. ● Some chance of contamination from propulsion unit. ● Needs manipulators for work tools.

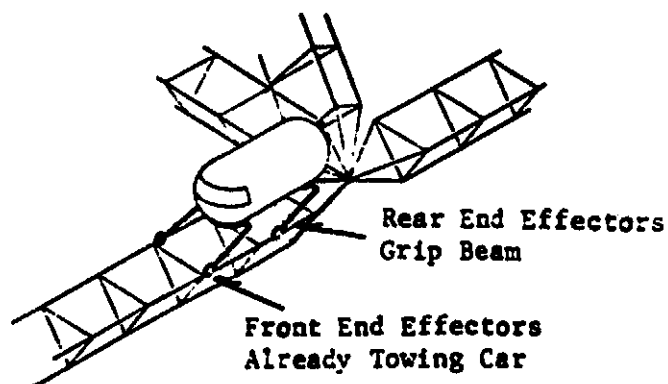
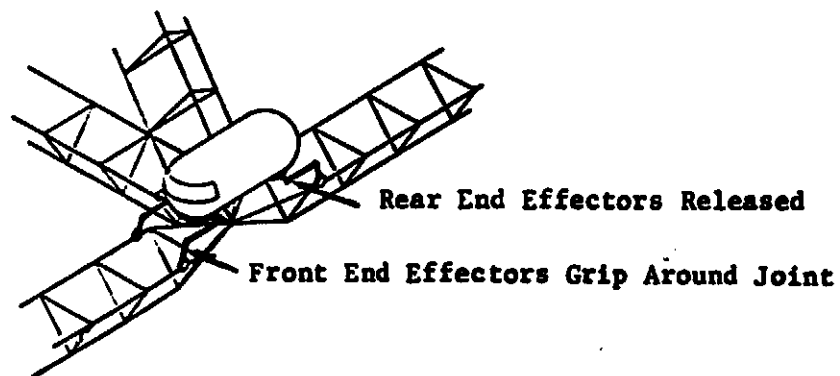
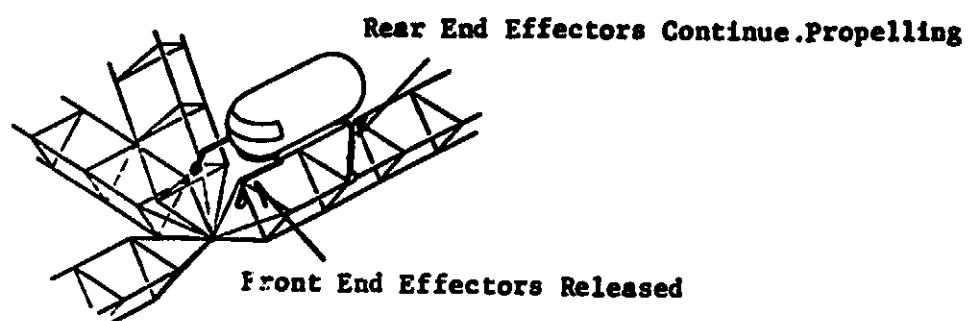
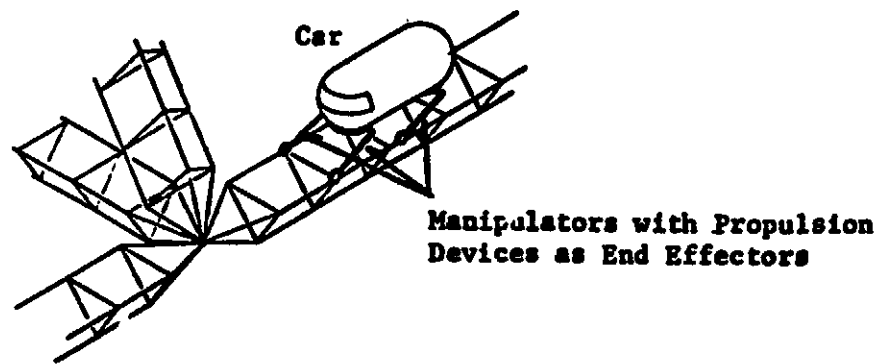
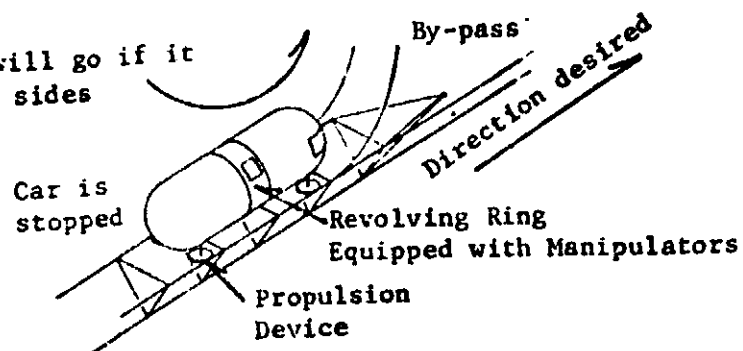


Figure 5.2.8-9 Beam Travel:

Direction car will go if it
doesn't switch sides



Disengage Propulsion Devices from Track

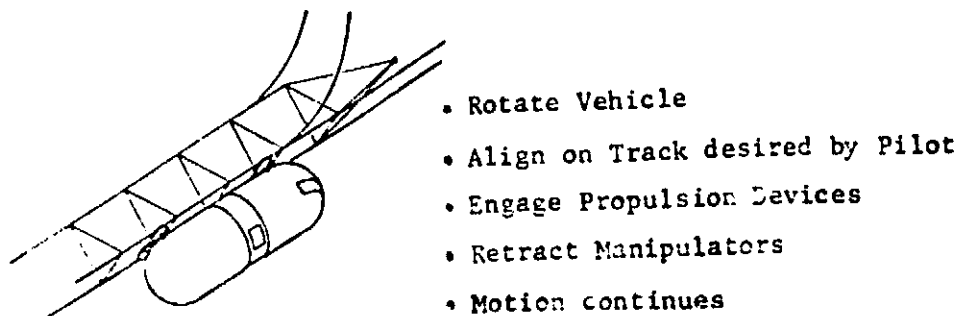
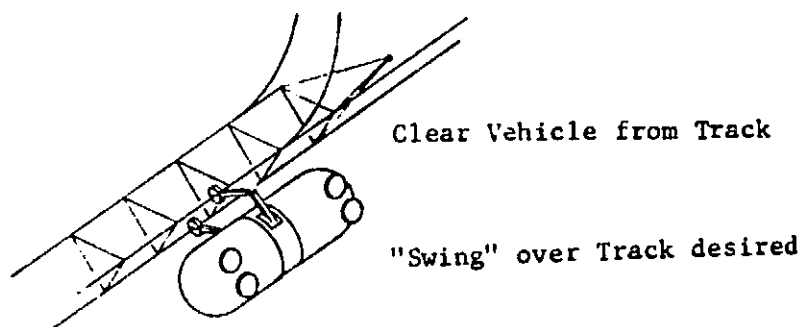
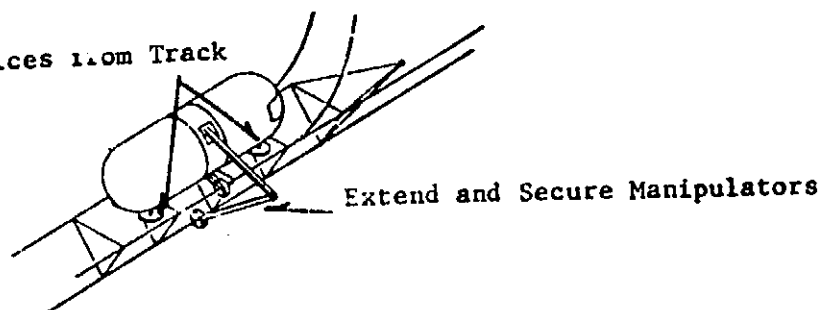


Figure 5.2.8-10 Static-Rail Changer

manipulator and a rotating ring as shown in the four plates of the Figure.

- c) Dynamic Rail Changer - The second method of changing sides (see Figure 5.2.8-11) does not need to stop to accomplish the change, but rather does so while moving. This method uses a "switching" arm equipped with a beam gripping device to accomplish this (as shown in the four plates).
- d) Combination Free-Flyer/Rail Vehicle - One configuration which is on the borderline between being considered as a rail system or as a free flyer is a free flying transport with beam gripping "landing gear" which it uses to "dock" with a construction site. Use of such a vehicle could do away with the need for a docking and receiving station for resupply vehicles. Before approaching a construction site this vehicle would put itself on a glide path which would bring it to interface with a beam "runway" (a structure which would gradually truncates into a structural beam of the construction site). After the vehicle has "docked" the landing gear would grip the beam and propel itself along as the previously described vehicle.

5.2.8.5 Subsystems - There are several key factors for each subsystem that will require specific definition to accomplish the next phase of studies and designs. Each subsystem are listed below with at least some of the criteria required identified. These criteria are necessary to establish size, power, mass properties, etc of the subsystems.

- Beam Propulsion System
 - acceleration
 - braking/deceleration
 - velocity
 - structure/transporter rail interface
 - structure/transporter power interface
- Transporter Size
 - number of astronauts required
 - identification of materials and tools to be transported
 - loads imposed on beams

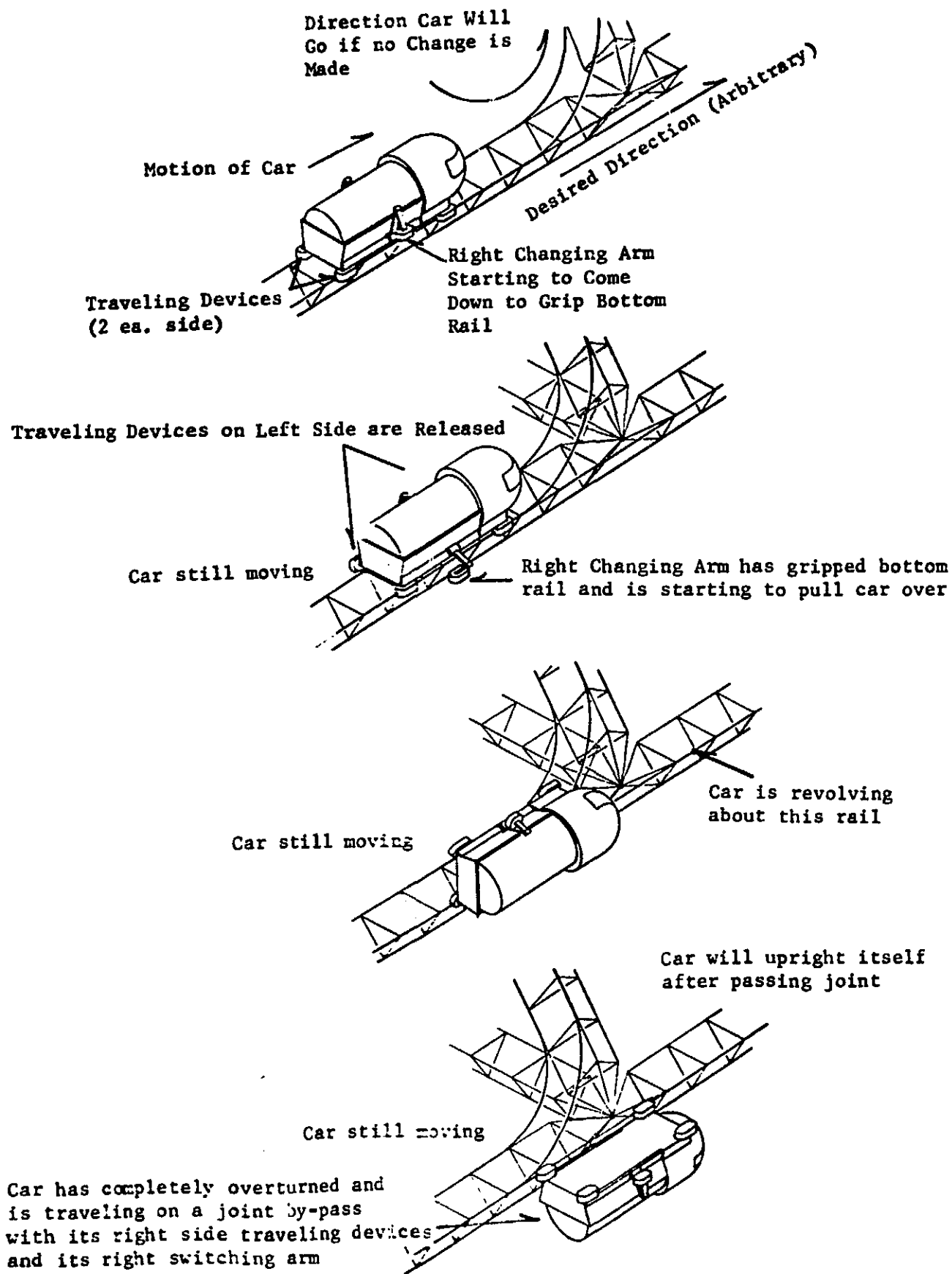


Figure 5.2.8-11 Dynamic Rail Changer

- Structure Support Equipment

- tasks to be performed during construction maintenance and inspection
- reach of manipulator arms (size of structure)
- end effector interfaces
- electrical power available
- inspection aids, cameras, optics, X-ray, etc
- special tools
- changeout of end effectors

5.2.8.6 Environmental Factors - The environments will have a major impact on the designs and influence the trade studies. These listed environments are the minimum that must be considered.

- Space vacuum
- Maximum and minimum temperatures
- Solar exposure
- Meteorite protection
- Operating cycles
- Operating life

5.2.8.7 Interface Factors

5.2.8.7.1 Launch Vehicle Requirements - The transporter must be designed to not only fit inside the launch vehicle but must be designed to maximize the weight density for launch. Completeness of assembly at launch must be weighed against the complexity and cost of space assembly of the transporter.

5.2.8.7.2 Servicing and Maintenance - The transporter design must consider servicing and maintenance in the overall trade studies. Several guidelines and tradeoffs listed below can assist the designer in his overall evaluation criteria.

- Brushless versus brush type motor (long life).
- Sealed versus unsealed lubricant applications for bearings, gears, etc. Influenced by life, loads, and type of space lubricant.
- Plug-in modules for space depot overhaul versus on-transporter repair.
- Human factors for ease of replacement or repair of transporter in space environment.
- Space depot overhaul of entire transporter versus on-structure repair.

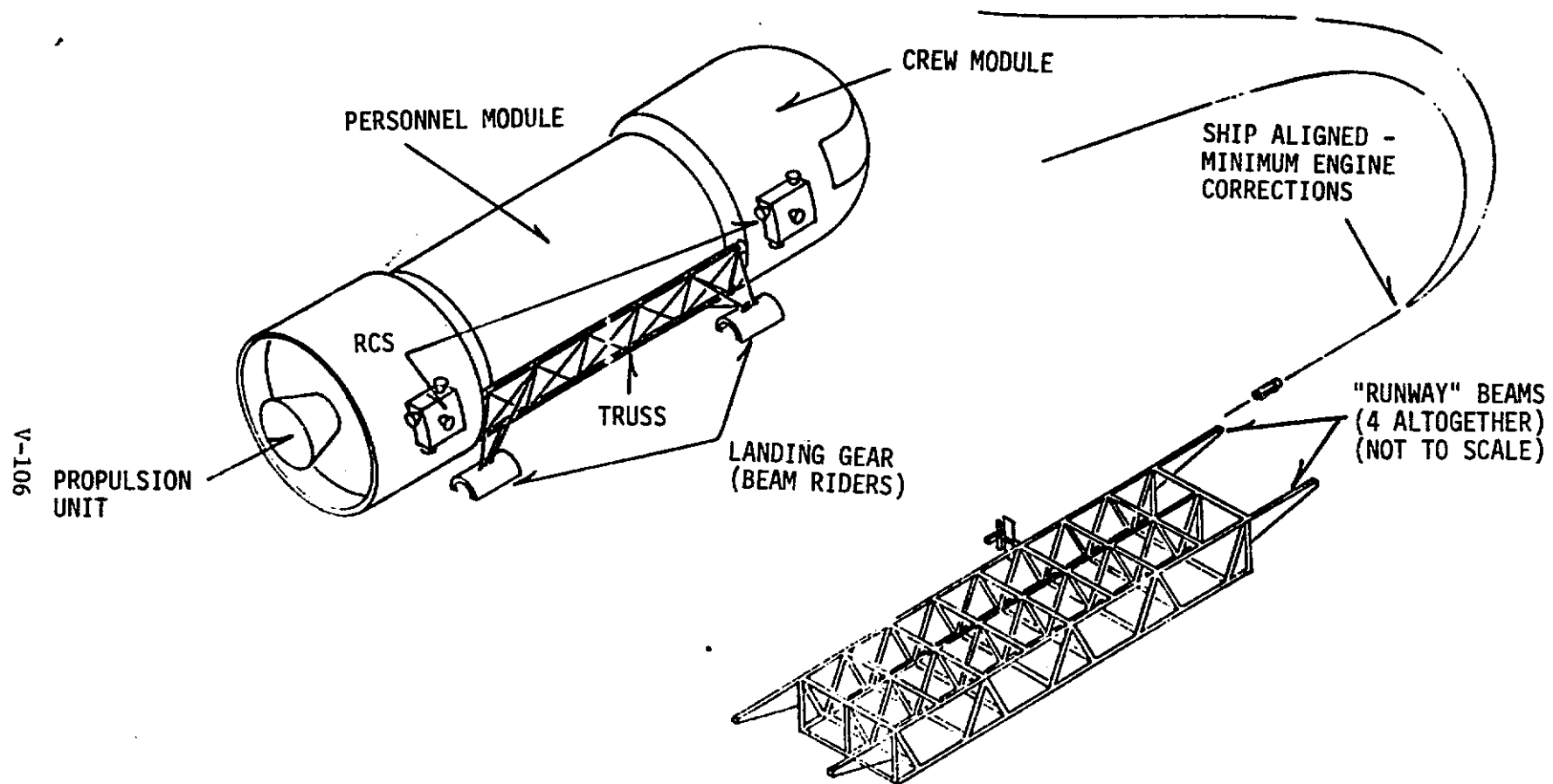


Figure 5.2.8-12 Combination Free Flyer/Rail Vehicle

5.2.8.8 Development Plan - Future activities recommended as a result of the conclusions reached in this preliminary evaluation are summarized in Figure 5.2.8-13. The schedule of activities as shown provides an indication of the long lead support required to define the technology needed for feasible development planning. The SRT item of primary interest is the attachment interface between the transport vehicle and the structure on which it moves. It is recommended that this interface effort be conducted as an independent research study which would address this technology area for all vehicles which may ride on or in some form of SPS structure. A major portion of this study would include the mode of energy or propulsion means used to translate the attached vehicles over structure. Other technology areas such as cab design, life support equipment, and cargo storage and handling should be developed on other programs with an earlier need date.

MILESTONE DESCRIPTIONS	SCHEDULE											
	77	78	79	80	81	82	83	84	85	86	87	88
● SYSTEM DEFINITION/EXPLORATORY TECHNOLOGY												
SYSTEM DEFINITION				—								
STRUCTURE INTERFACE/PRELIM PROPULSION DESIGN		—										
TRADE STUDIES/PRELIMINARY DESIGN SPEC					—							
◇ COMMIT TO TECHNOLOGY ADVANCEMENT				▽								
● TECHNOLOGY ADVANCEMENT												
- GROUND BASED DEVELOPMENT												
ENERGY SUPPORT EQUIPMENT CRITERIA						—						
- SPACE EXPERIMENTS												
FINAL TRADE STUDIES AND DESIGN SPEC										—		
- SPACE SUBSCALE SYSTEM EVALUATION												
◇ COMMIT TO SYSTEM DEVELOPMENT												▽
● SYSTEM DEVELOPMENT												

Figure 5.2.8-13 Structure-Attached Transporter Development Schedule

5.2.8.9.1 Trade Studies - Previous paragraphs have described several concepts of transporters and identified some inherent advantages and disadvantages of each type. These studies were of sufficient depth to select the beam attached approach as the most viable candidate for further trade studies. The next logical step is to pursue the identified designs in much further depth with the following items evaluated as a minimum.

- Transporter size and complexity to accommodate two to ten astronauts.
- Transporter size, retention requirement and handling needs for various materials, components and tools to perform construction and maintenance tasks.
- Impact of various designs on the basic beam structure design for rails, joint bypasses, special docking facilities, etc.
- Interface requirements with the space structure power system for plug-in rechargeable power packs versus bus bar type power system.
- Flexibility of each approach to accomplish the basic functions of transporting, construction and maintenance, and use of multipurpose devices such as manipulator arms doubling as legs for the motive actuators, as well as tools for construction and maintenance.
- Crew involvement in traversing structure.
- Crew environment; i.e., shirtsleeve vs space.

As the preceding discussion suggests, several significant trade studies are required to define the design details of a structure-attached transport system. The impact of the design requirements for the transporter upon the design of the basic beam may be critical; beam geometry and overall beam strength may be more strongly influenced by the transport system than by general SPS structural requirements.

The requirement for and design of joint bypass systems must be more firmly established. Depending upon the eventual configuration of the construction base, the number of bypasses needed can be minimal or relatively significant in terms of added structural mass and complexity.

Further definition of the OCSE transportation fleet is required, so that the number and type of each class of vehicle (surface-attached, free-flying, hybrids) can be fitted to the particular tasks to be performed. This functional definition can have an impact upon the factors mentioned above: beam design, structural requirements, bypass design, and the construction base configuration.

5.2.3.9.2 Supporting Research and Technology - Some of the aspects of the transporters need to be addressed in the near future, both because of the progress on the beam structure design and long lead research required. Other aspects can and should be delayed in starting either because the technology is now known, or interfacing structure or equipments are in too early of a development status of their own to make it meaningful or cost effective to design that part of the transporter. This paragraph will categorize the various portions of the vehicle and the following paragraph will establish the schedule for addressing the design phases.

- Items requiring near term action - 1978 thru 1980
 - Since there are several ongoing contracts on the design of the structure and the beam builders, an interface between the beams and the propulsion unit must be established. This means that preliminary designs of the wheels, rails, and transporter induced loads to the structure, need to be completely defined so that interface can be finalized.
 - Overall transporter system definition needs to be generated. This will include the specific tasks to be accomplished by the transporter during construction, structure and equipment maintenance, and space structure system inspection. Also any special requirements for personnel/material transporting, other than used by the transporter, should be enumerated.
 - Additional trade studies should be conducted in the latter portion of this period to establish a preliminary transporter concept and generate a preliminary design specification.
- Intermediate term actions - 1981 thru 1984
 - Ground and space demonstration models of the beams and propulsion modules should be built and tested during this time frame.
 - The development of solar panels, solar concentrators and other energy conversion equipments will be continuing over the next few years. This development in conjunction with the structure development will establish the interface requirements of the transporter in the area of manipulator arm reach and motions, and the types and

motions of the end effectors. These requirements need to be definitized and models made and tested to verify interface compatibility both on earth and in space.

- Several elements of the design such as manipulators, motors, lubricants, other materials, etc will be undergoing a natural evolution of improvements. In the 1984 era these many elements need to be researched and candidates selected for the next phase of development.
- A final trade study and design specification should be completed by the end of this period.
- Long term development - 1985 thru 1995
 - A design, fabrication and space demonstration of all the functional elements of the transporter should be accomplished on a prototype vehicle by the end of 1987. At this time a commitment to full system development will be made.
 - From 1988 thru 1994 design improvements, specification modifications, technology advances, etc would be incorporated in a development/qualification phase of the transporter so a production design would be completed for fabrication in 1995.

5.2.9 Storage Panels

5.2.9.1 Introduction - A storage panel is a tray which holds end effectors and tools until they are needed by the manipulator which the storage panel serves. Only manipulators which use a number of different end effectors in accomplishing a task need storage panels. Storage panels have been used in conjunction with manipulators for undersea work by the U.S. Navy. A storage panel developed by Battelle, called a work systems package, is a matrix of tubular aluminum bins which hold hydraulically operated tools designed for undersea work. The work systems package contains tools such as a chipping hammer, wrench, jack, and cable cutter. Possible candidates for tools used in space construction include cable cutters, welding tools, cable tying devices, and alignment devices.

5.2.9.2 Operational Discussion - The storage panel will most likely be a passive unit, the manipulator performing the actual tasks of finding the location of the desired end effector, grasping the end effector, removing the end effector from the tray, replacing the end effector in the correct location, and releasing the end effector.

5.2.9.3 Crew Participation - The manipulator operator is the most likely candidate for directing the changing of end effectors. The manipulator might possibly be linked to a keyboard by which the operator could select the next end effector by pressing a button marked with the name of that end effector. The keyboard would call out the stored coordinates (corresponding to that end effector) from its memory and use them to instruct the manipulator (first storing the end effector already on the manipulator).

5.2.9.4 Concepts - The securing of an end effector in the storage panel could be accomplished with the use of a double brush system as shown in Figure 5.2.9-1.

If the storage panel is stationary in relation to the manipulator it serves, an optimal design of the storage panel would be a curved surface to correspond to the arc described by the manipulator.

If the job performed by the manipulator requires that end effectors be used in rotation, an optimal design of the storage panel would be a carrousel.

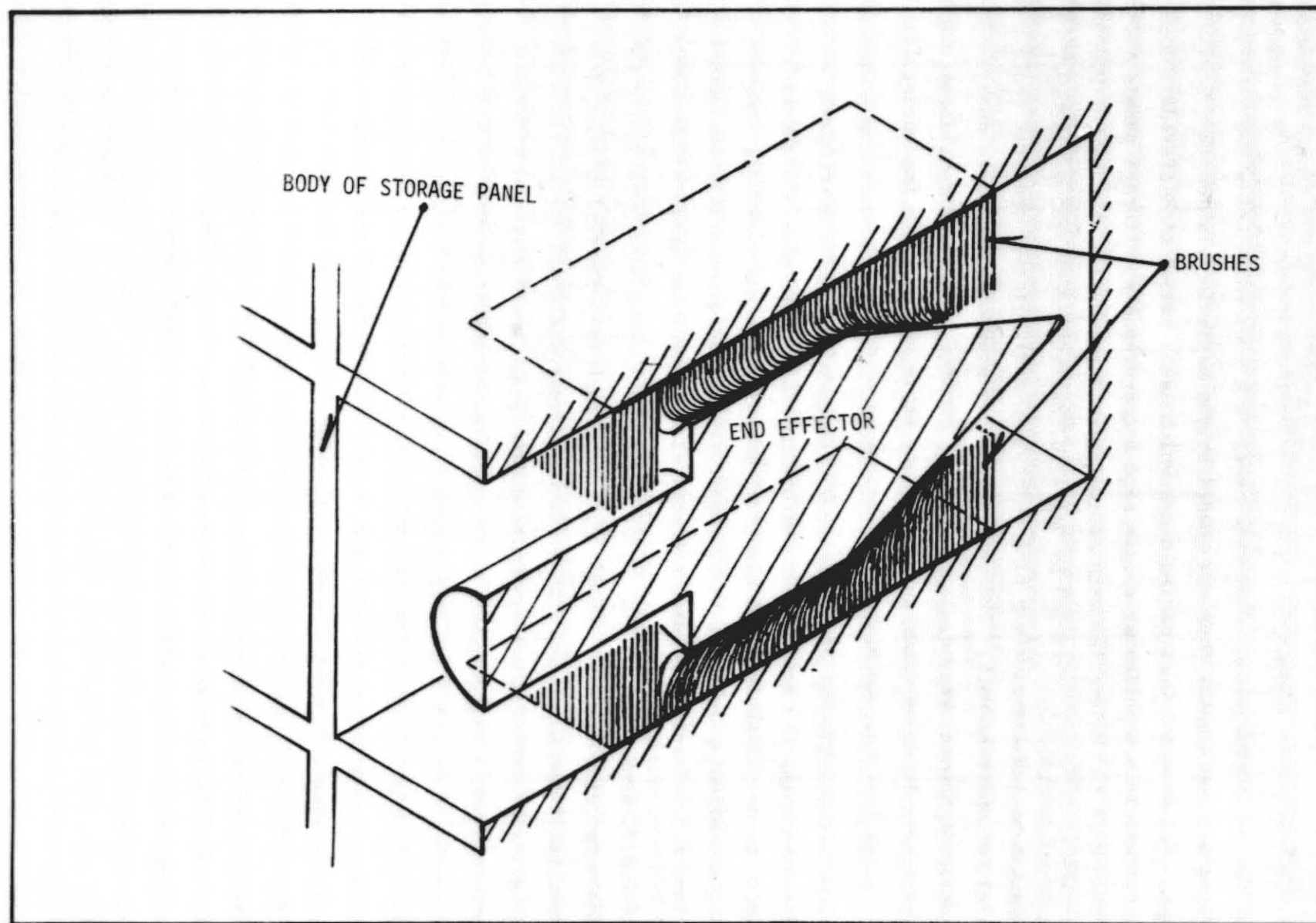


Figure 5.2.9-1 Double Brush End Effector Securing System

Table 5.2.9-1 Factors Influencing Design of Storage Panel

- **OPERATIONAL FACTORS**
 - Number of end effectors
 - Size of end effectors
 - Frequency of use of each end effector
 - Size of manipulator
 - Working volume of manipulator
 - Placed for least interference
 - Placed for easiest accessibility
 - Fastening Techniques
- **ENVIRONMENTAL FACTORS**
 - Susceptibility of tools to damage by environment
 - Outgassing (change in hardness)
 - Micrometeoroid
 - Thermal
 - Charging

5.2.9.8 Development Plan - The future activities recommended as a result of the study and the restrictions assumed at this time have been summarized and shown in Figure 5.2.9-2. The development of OCSE storage panels must be accomplished in a cost effective, cohesive, and integrated approach. This is difficult in this area since many of the storage panels would be dedicated to specific pieces of hardware. However, many of the requirements for OCSE storage will be the same and an effort is required that will define and analyze desired techniques to minimize duplication of studies and potential number of storage panels which accomplish the same functional task. Therefore, the continuing effort should make maximum use of results from previous and ongoing space programs and develop a designer's manual for stowage techniques which would help assure that new concept developments satisfy the broadest practical scope of SPS program guidelines relating to interfaces, common equipment usage and crew safety.

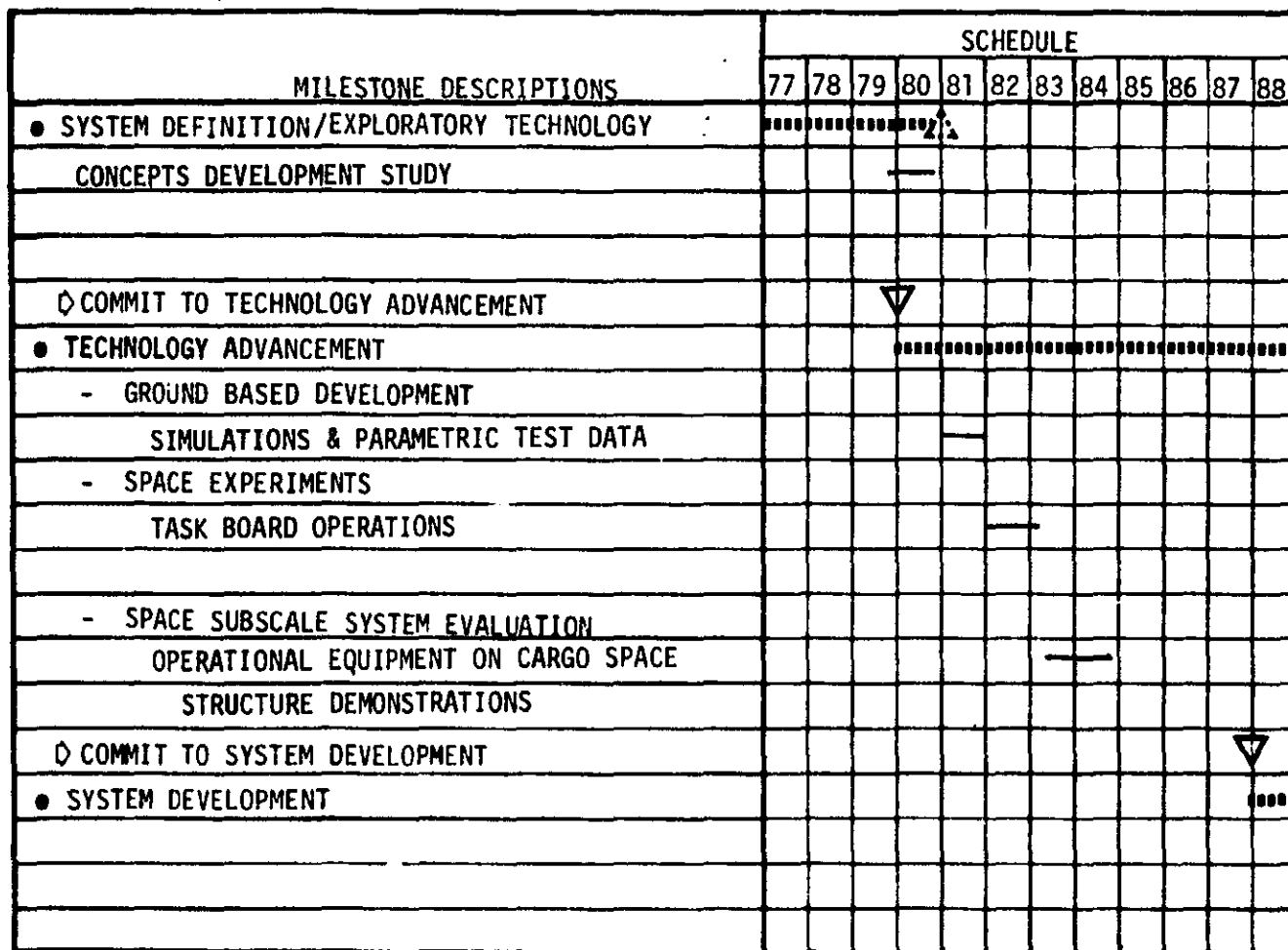


Figure 5.2.9-2 OCSE Storage Panels Development Schedule

5.2.10 Personnel/Material Transporter, Free Flying

5.2.10.1 Introduction - Tasks involving personnel/material transportation in the vicinity of an SPS which cannot be carried out by structure attached vehicles would make use of free flyers. Discussed here are six possible personnel/material transporters for SPS use.

5.2.10.2 Operational Discussion - There will be a multitude of SPS construction tasks which could be performed with the use of free flyers; therefore, there will be a wide range of different requirements imposed on the free flyers (e.g., required environment, interfaces and payload capacity). Potential tasks can be classified into five general types: 1) construction/maintenance; 2) reconnaissance; 3) crew rotation; 4) material supply; and 5) rescue.

5.2.10.3 Crew Participation - The term "personnel/material transporter" as used here refers to a man piloted vehicle capable of transporting men and materials.

5.2.10.4 Concepts - The smallest personnel/material transporter that has been proposed is the Manned Maneuvering Unit (MMU). The MMU is an extravehicular propulsion unit that is worn and controlled by one astronaut who may carry tool kits and other small packages. Figure 5.2.10-1 shows an astronaut wearing an MMU.

A transporter concept which may carry up to two astronauts and some small packages and tools is the pressurized, free-flying ECWS. This vehicle could be equipped with manipulator arms by which the operator could perform tasks. Figure 5.2.10-2 shows four different configurations of pressurized, free-flying ECWS.

A free-flyer designed for suited astronauts is the open platform, free-flying ECWS. This platform would transport up to three astronauts and their equipment. The platform uses grapple devices to hold its attitude at a worksite. Figure 5.2.10-3 shows an open platform, free-flying ECWS proposed by Westinghouse.

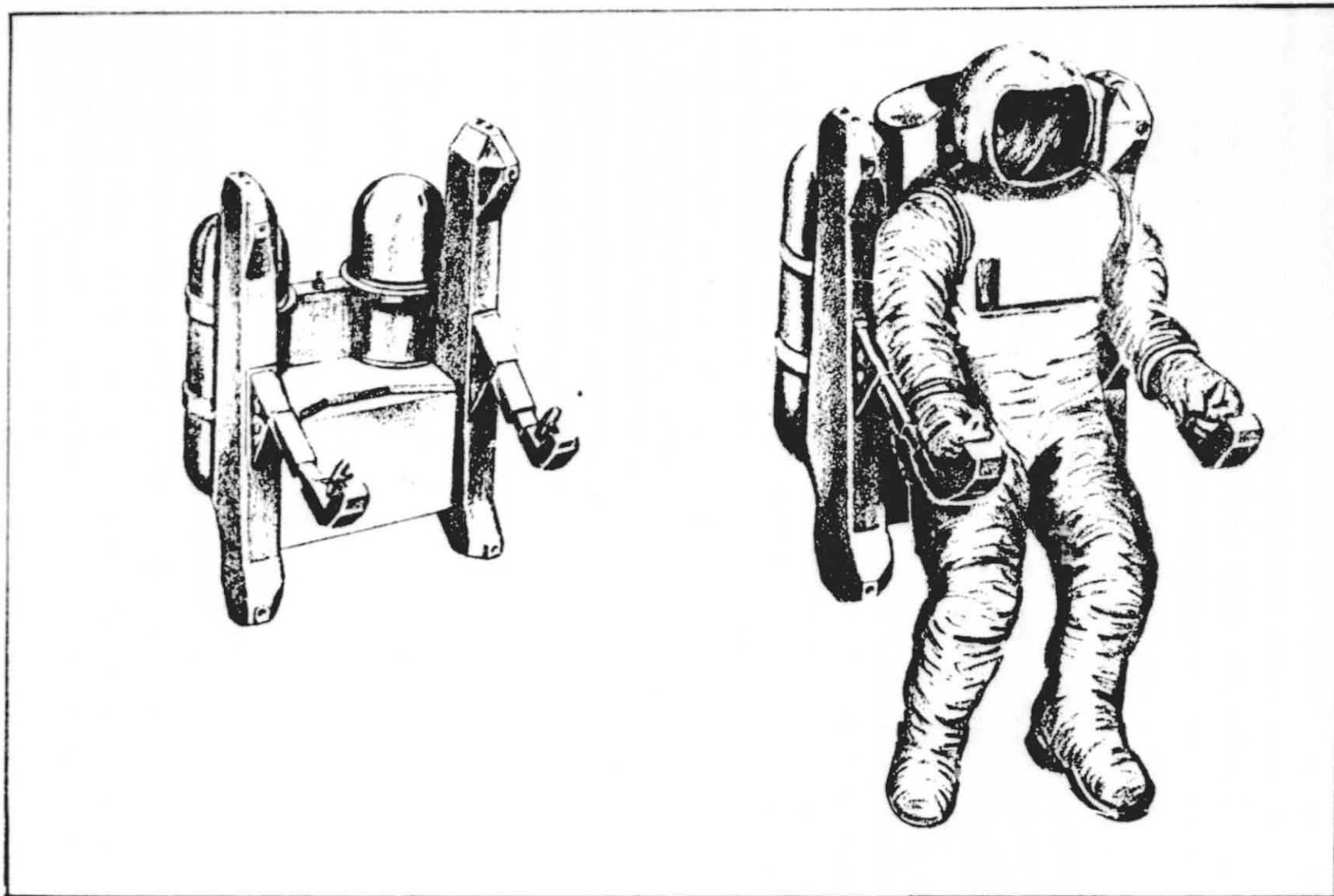


Figure 5.2.10-1 Manned Maneuvering Unit

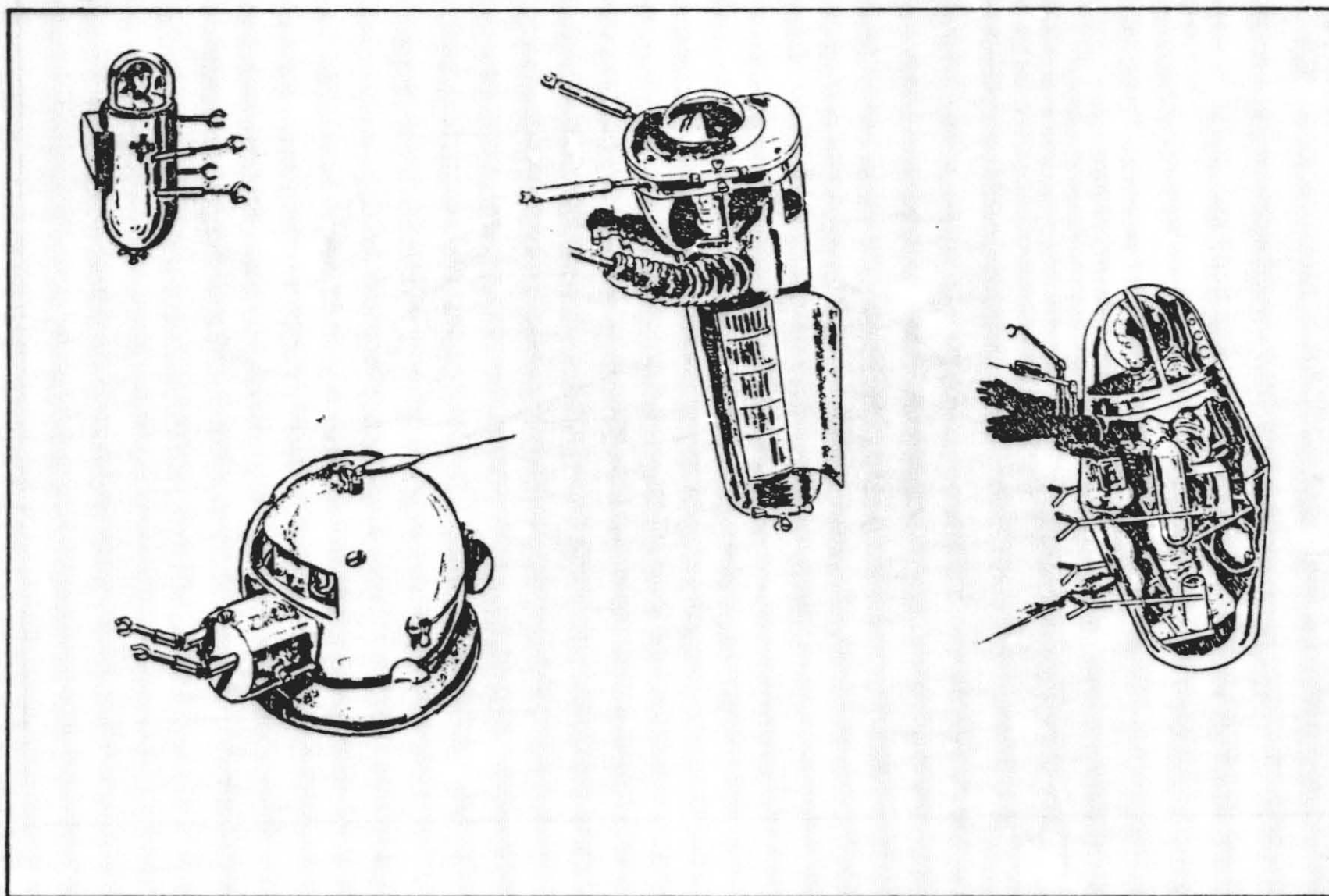
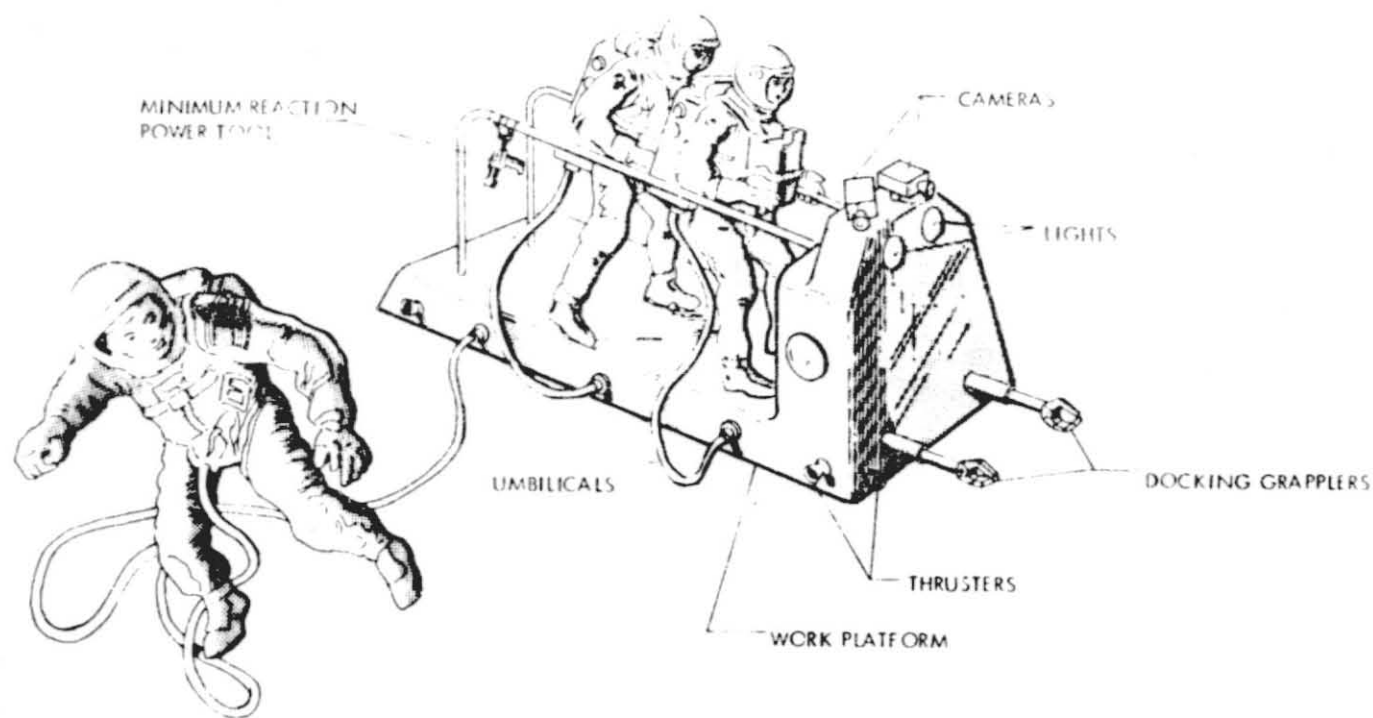


Figure 5.2.10-2 Pressurized, Free-Flying ECWS



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Figure 5.2.10-3 Westinghouse Open Platform ECWS

Orbital transfer vehicles, after having transported men and materials from LEO to GEO, could be used for personnel/material transport in the vicinity of the SPS. JSC has proposed three configurations of OTVs. The simplest, designed for satellite maintenance and also as a pilot's station for larger OTV configurations, is the crew module. The crew module, shown in Figure 5.2.10-4, is 4.82 m long, 4.42 m in diameter, and can support two to four men. If the crew module is docked with a crew rotation passenger module the result is a personnel orbit transfer vehicle. The POTV shown in Figure 5.2.10-5 has a 75-man capacity. Docking the crew module with a cargo module results in a cargo orbit transfer vehicle. The COTV shown in Figure 5.2.10-6 has a 250 ton payload capacity.

5.2.10.5 Subsystems - Table 5.2.10-1 shows the modifications or additions that each of the six concepts requires for its efficient application in the five general tasks.

5.2.10.6 Environmental Factors - Environments to which all free-flyers will be exposed and therefore will affect their design include the following:

- Space vacuum
- Maximum and minimum temperatures
- Solar exposure
- Meteoroid impact
- Operating cycles
- Operating life

5.2.10.7 Interface Factors - JSC's concepts for the Crew Module, POTV, and COTV require that they be launched in sections and assembled in orbit. The MMU, pressurized ECWS, and unpressurized ECWS have or should have a launch density high enough to allow them to be launched as units.

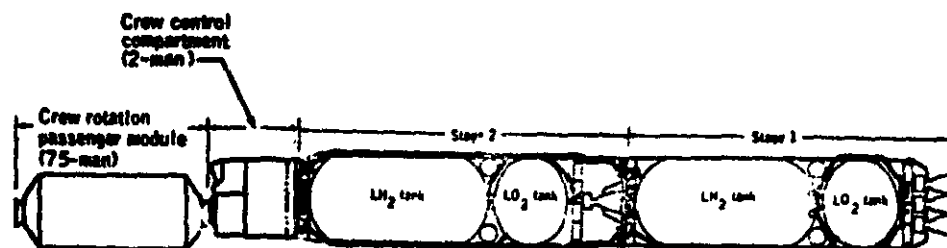


Figure 5.2.10-5 Personnel Orbital Transfer Vehicle

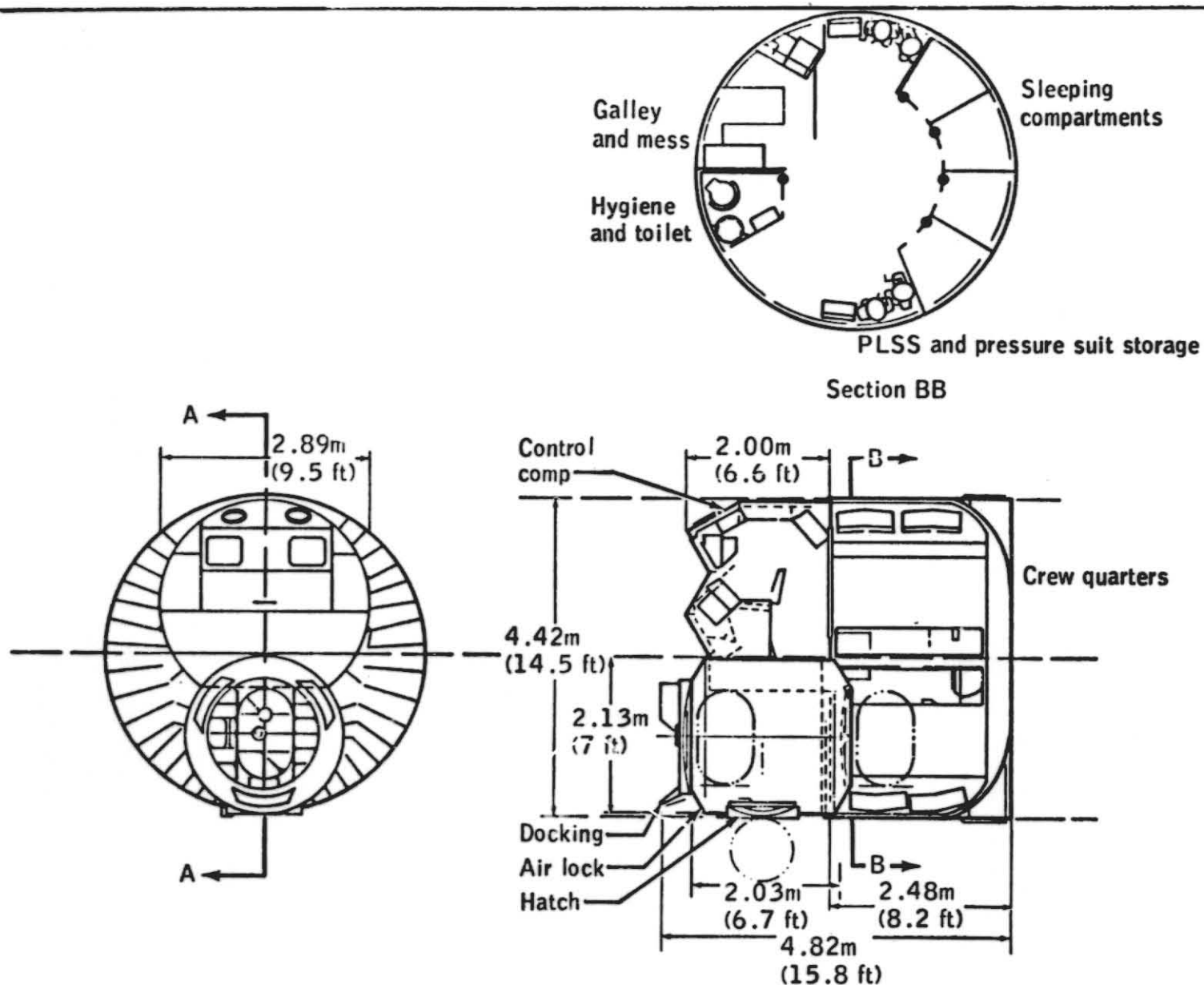
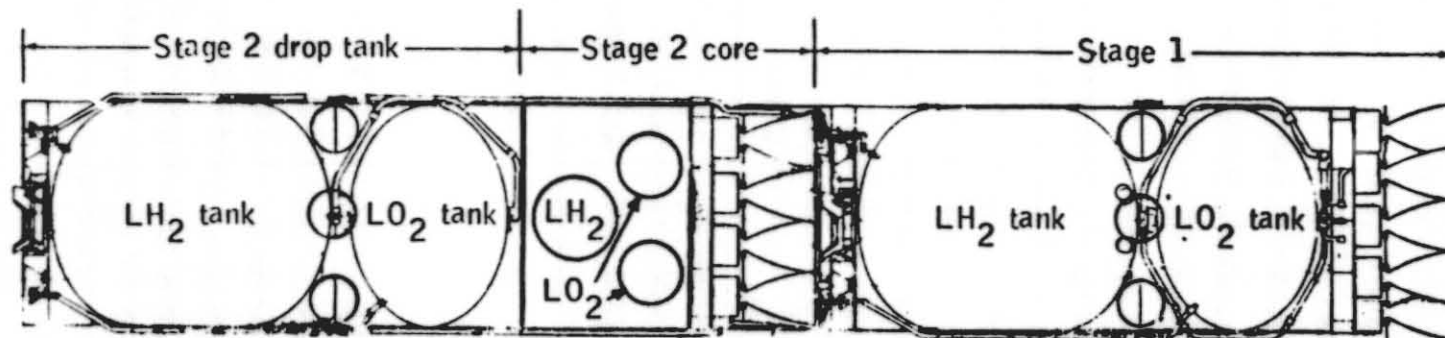


Figure 5.2.10-4 Crew Module



2-1/2 stage LO₂/LH₂
 Life: 30 missions
 Payload: 250 tons
 ≈\$10M/ft

Length: 48M
 Diam: 8.4M
 Total weight: 510 tons
 Propellant weight: 475 tons

Table 5.2.10-1 Concept Proficiency for Five Tasks

CONCEPT (# CREW)	CONSTRUCTION/ MAINTENANCE	RECONNAISSANCE	CREW ROTATION	MATERIAL SUPPLY	RESCUE
Manned Maneuvering Unit (1) A	Small tool kit with power pack.	Direct viewing. Hand-held viewing devices.	No change. Possibly multiple astronaut airlock needed.	Limited to small hand carried items.	Shuttle rescue system.
Pressurized Free- flying ECWS (2) B	Storage panel of proper end effectors.	Direct viewing. TV monitoring. Possibly hand- held viewing devices.	Limited from pres- surized vehicle to pressurized vehicle.	Protection for small packages. Large packages outside.	Limited
Open Platform Free Flying ECWS (3) C	Proper equipment and tools.	Direct viewing. Hand-held viewing devices.	No change.	No protection. Large packages.	Shuttle rescue system. Extra life support systems. Rescue equipment.
Crew Module (4) D	Small change. First mission possibly for sat- ellite mainten- ance.	Direct viewing. TV monitoring. Possibly hand- held viewing devices.	No change.	Protection for medium-sized packages.	Subsystems of A.
COTV (4) E	Large capacity for tools and parts. Subsystems of A, B, C, D.	Large modifica- tions required.	N/A	No change. Designed for this purpose.	N/A
POTV F	N/A	Direct viewing. TV monitoring. Possibly hand- held viewing devices.	Designed for this purpose.	Limited to carry- on packages. Protection.	Large rescue operations. Subsystems of A.

5.2.10.8 Development Plan - Future activities recommended for the timely development of Free Flying Transporters are summarized in Figure 5.2.10-7. A considerable amount of the technology to date is relevant to the manned free flying transporter. For example, the MMU, Apollo LEM and CM/SM and Shuttle POTS are expected to provide a number of flight qualified hardware necessary for this vehicle; i.e., propulsion, life support equipment, docking and crew transfer mechanism, GN&C, communications and indirect viewing. Commonality of hardware is also assumed here where the structural portion which houses the man is considered a duplicate to that used on the cherry picker.

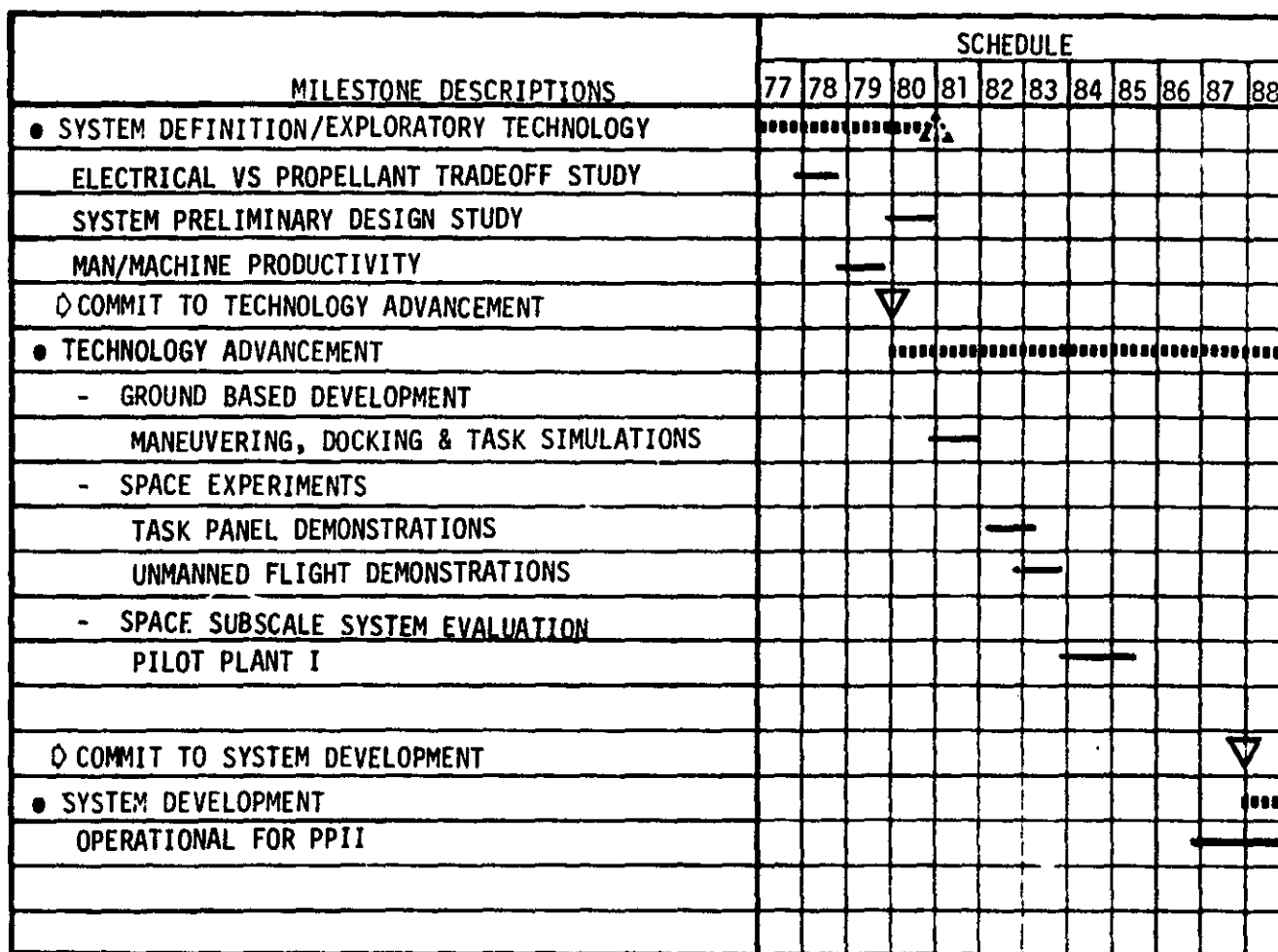


Figure 5.2.10-7 Free Flying Transporters Development Schedule

5.2.11 EVA Module

5.2.11.1 Introduction - In order to provide for extravehicular activities (EVA) an EVA module was identified which would house all of the associated EVA equipment hardware, its checkout facility, recharge, stowage, and donning and doffing station, and an airlock to gain access to the vacuum environment. Each module should be capable of supporting two to six men and their associated hardware to provide EVA capability on quick notice (24 hr/day). This quick response requirement identified one of the prime design drivers associated with the EVA module. Another design requirement for the module has the crew prebreathing an oxygen atmosphere prior to suited EVAs. Two potential solutions to this problem which lie at the opposite ends of the resolution range were proposed which include: design, build and test a pressurized suit which would be operational at 760 mmHg (14.7 psia) or use an interim pressurized module maintained at 196 mmHg (3.85 psia) of O₂ from which the EVA acclimated crew can suit up and perform quick response EVAs. Since an ongoing study, *Extravehicular Crewman Work System (ECWS)*, Contract NAS9-15290, is looking at the 760 mmHg pressure suit concept, this study looked at the multicrew, interim pressurized (196 mmHg) module concept.

5.2.11.2 Functional Discussion - The functional requirements for an EVA module were derived from two primary sources--documents provided at the study start, Ref. JSC-11568 and JSC-11867, and the fallout of man's participation developed in Part I of this study. The following paragraphs present this information as it relates to the development of an EVA module concept.

5.2.11.2.1 General - The objective of this effort was to conceive an EVA module configuration and options which would satisfy the needs of the construction crews working in an EVA mode. The approach used was to match potential construction and assembly tasks with EVA capability, identify hardware and integrate it to be compatible with other proposed facilities and structures. The scope and complexity of the interactions and requirements associated with the EVA module coupled with the limited depth of the present study makes it inappropriate to be too absolute at this time. However, the thrust was to propose typical concepts which appear to be technically feasible in that no design or operational problems were encountered that did not appear

amenable to solution. The concept proposed has economic viability and system feasibility which obviously depends somewhat on a combination of technology advancement and cost of competitive sources.

5.2.11.2.2 Guidelines and Assumptions - Within the limitations of the study and based on related ongoing studies, the following guidelines and assumptions are presented:

- a) The SPS will be designed in a manner to optimize participation of man in its fabrication, assembly, and operation.
- b) EVA capability will be provided for unique nonrepetitive or for contingency operations.
- c) Extravehicular activities (EVA) in the SPS program will be defined as all activities which require the crewmen to don space suits and perform work activities external to the pressurized habitable facilities.
- d) Intravehicular activities (IVA) will be defined as those activities which take place within pressurized areas of habitable facilities.
- e) EVA crewmen will be required to prebreathe for approximately three hours on an O₂ atmosphere having five percent or less of N₂ by volume prior to suited EVAs.
- f) Airlocks will be capable of being depressurized by either pumpdown to 0.2 psia or by dumping to space.
- g) Airlocks to space environment will be sized for a minimum of three-man occupancy.
- h) Assumptions made relating to EVA operations which impact the EVA module configuration are as follows:
 - 1) EVA classes:
 - planned EVA - activities planned and scheduled during orbital construction
 - unscheduled EVA - activities not scheduled, but available on an as-required basis
 - contingency EVA - activities required to effect safe conditions for both construction crew and EVA crew

2) Crew shifts:

- four to six crew members per EVA module
- six hours on, six hours off, six hours on and six hours off
- thirteen days, six on, one off, six on and rotate
- maximum continuous EVA of three hours (for scheduled EVA only)

3) Crew tasks:

- construction equipment maintenance and repair
- assembly monitor, alignment, fasten, adjust, checkout
- EVA crew rescue
- initial setup and assemble of construction facilities, jigs and equipment

4) EVA safety:

- routine EVA crews will consist of two crewmen EVA simultaneously
- when two crewmen are EVA simultaneously in same area, no backup suited crewman will be required in airlock
- backup of individual crewman using MMU, if required, will be supplied by a second MMU
- continuous visual surveillance of EVA crewmen will be possible from control center (either directly or by TV)
- continuous voice contact will be provided between EVA crewmen and the control center
- EVA work will not be performed in an unrestrained condition except for contingency or emergency situations where restraints may not be available

5.2.11.2.3 Applications - The primary application of the EVA module is as a support facility for EVA crew and equipment personnel such as cherry pickers, MMUs, etc. A secondary application for the EVA module could be as small component repair facility. Since a number of the failed components requiring replacement are removed by the EVA crew, they could also inspect the failed component and determine if repair would be possible. This application would be most critical to SPS construction equipment since downtime is critical to the overall assembly sequence.

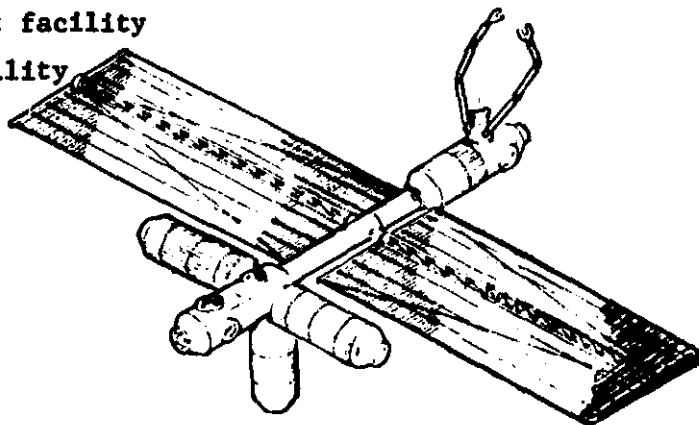
5.2.11.2.4 Trade Studies - In the process of working the EVA module concepts and technical feasibility two major trade studies were identified.

The first one deals with the productivity of man in the EVA mode versus that of a machine in either the remote manned or autonomous control mode. The other trade study identified was that of shielding or wall thickness versus crew radiation exposure. A number of different trade parameters included in this type of trade study are EVA duration, tour of duty, orbit altitude, sun's state, crew size, structure of crew rotation base, etc.

5.2.11.3 Crew Participation - The purpose of the EVA module is to provide an effective man/machine interface in going from the shirtsleeved crew to his performance of an EVA task. The prime requirement which bounds the crew participation is the one that states that EVA capability will be provided for unique nonrepetitive type tasks or for contingency operations. The EVA module is a primary vehicle for supporting EVA operations and as such will take advantage of man's capabilities wherever feasible for both control and maintenance of operational functions.

5.2.11.4 Concepts - The basic EVA module configuration concept agreed upon was an interim pressurized module outfitted to provide spacecraft docking, life support, EVA equipment storage and servicing, airlocks, etc. Some of the spacecraft used on past programs such as the Apollo CM, or the Skylab MDA/AM could be modified and used as the EVA module. Basic options considered at this time included choices between attached or free flying and operational in LEO or LEO and GEO. For this study the facilities cluster attached configuration was selected. Space vehicles that make up the cluster include the following modules:

- Orbital construction and support equipment facility
- Logistics facility
- Integration management facility
- Crew habitability facility
- Construction base



The most feasible location selection for attachment of the EVA module within the cluster grouping was the crew habitability facility. A review of past space programs resulted in selecting a space vehicle very similar to the MDA/AM configuration., which best met the EVA module requirement identified in 5.2.11.2.2. Looking into the needs of an EVA module in more depth resulted in a general list of EVA module capabilities and hardware as follows:

- Crew Living Area
 - sleep area 4 to 6 personnel
 - head and shower provisions
 - eating area
 - control center, monitor EVA, learning terminal
 - EVA equipment storage, service and checkout area
- Airlock Area
 - storage, service, donning and doffing provisions for EMUs (3 to 5)
 - handrails and footrails
 - portable O₂ systems
 - ECLSS panel
 - hatch port (2 or 3)
 - pressure control
 - EVA umbilicals
- External Module
 - storage, service, donning and doffing station for MMUs
 - docking ports
 - portable lights
 - tethers
 - transport platforms (personnel and materials)
 - EVA hand tools storage and checkout

Using this data a flow schematic was prepared as shown in Figure 5.2.11-1 which represents most of the items identified above.

Two to six EVA crew members will live continuously for a period of 13 days in a one-gas system (O₂) at a pressure of 196 mmHg (3.85 psia). These men will enter and leave on a crew rotation basis through the airlock located between the EVA module and the crew habitability facility. The crew quarters contain the sleep compartment, waste management/shower, wardroom

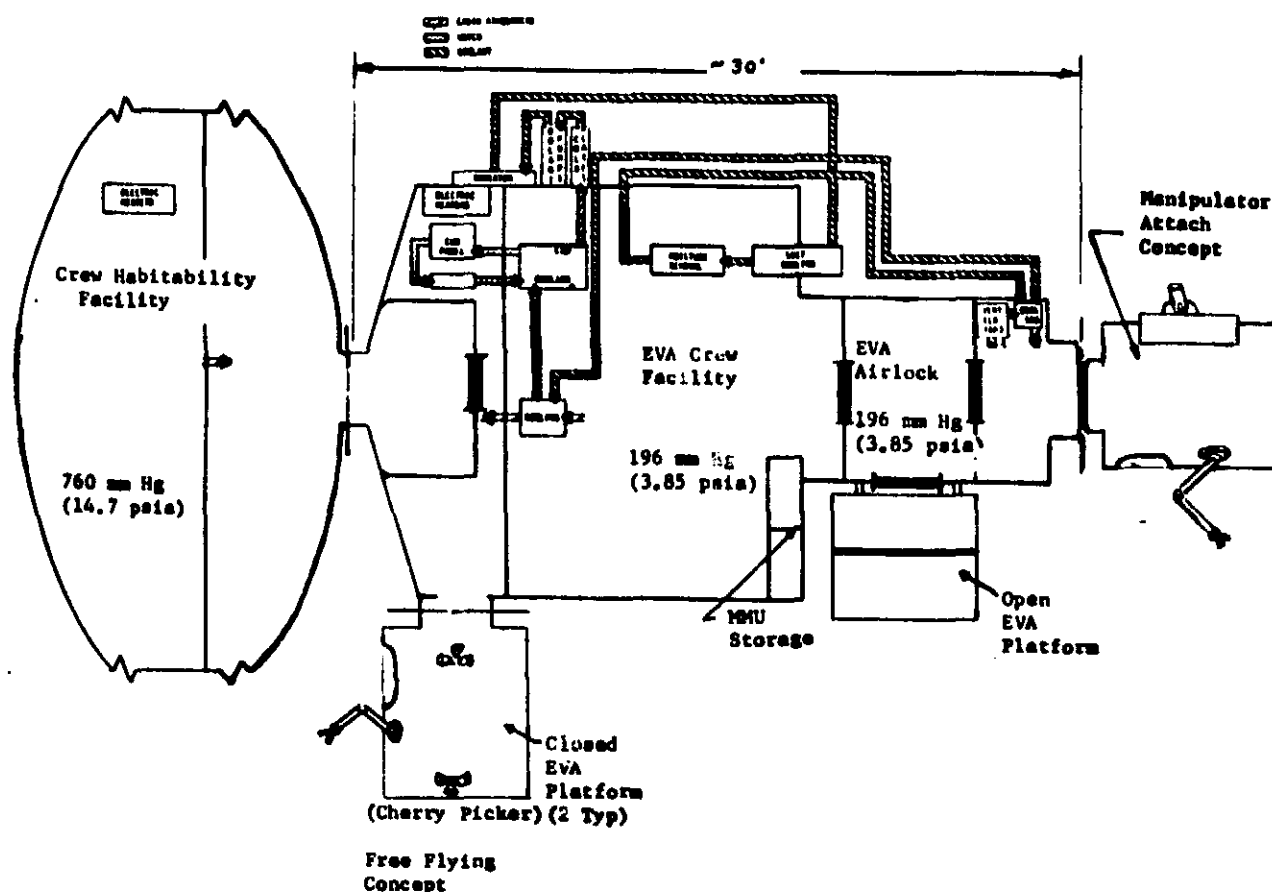


Figure 5.2.11-1 EVA Module Flow Schematic

and work area and provides the crew with areas from which they can conduct their normal daily activities and special tasks under living conditions similar to those experienced at one-g. All living provisions will be provided by the EVA module with the exception of oxygen, food/preparation, clean clothes and contingency items. These special items will be provided on an as-needed basis from the habitability facility through a small airlock. Two modes of EVA transportation are provided--one is the open platform from which a suited astronaut attached to an umbilical or MMU can perform EVA. The other is the closed platform like a cherry picker which would be attached to a manipulator or could even be free flying.

5.2.11.5 Subsystems - The major subsystems identified with the proposed EVA module are presented in Table 5.2.11-1.

Table 5.2.11-1 EVA Module Subsystems

SUBSYSTEMS	SIZE	WEIGHT
Structure:		
Shell	10 ft dia x 28 ft lg	-
Docking Ports	3 ft dia x 2 ft lg	-
Airlocks	5 ft dia	-
Crew Quarters:		
Wardroom		-
Sleep Area		-
Waste Management		-
Work Area		-
Life Support:		
O ₂ Emergency Storage	2 - 3 ft dia tanks	(100 lb)
O ₂ Supply from Cluster	1' x 1' x 1'	(20 lb)
O ₂ Pressure Control	0.5' x 0.5' x 0.5'	(15 lb)
M61 Sieve Sys (CO ₂)	3' x 3' x 2'	(150 lb)
Airlocks:		
Hatches (~7)		
Atmos Pump-down System		(150 lb)
Equipment Recharge Station		
EVA:		
Umbilicals		
Suits		
MMU		
Open Platform	3' x 6' x 2'	(200 lb)
Cherry Picker	4' dia x 6' high	(400 lb)
EVA MODULE TOTAL	10 ft dia x 28 ft lg	25,000 lbs

5.2.11.6 Environmental Factors - The major environmental factor affecting the EVA module design is radiation impacts. While there is very little problem with radiation in low earth orbit, any EVA tasks required in GEO would be a different problem. One of the most apparent solutions for man to survive the hazards of the radiation environments in high altitude orbits is the effective use of shields. An ongoing NASA study, ECWS, NAS9-15296, is looking at this problem area in great detail. Data from this study and from studies relating to SPS construction bases in GEO will be available for future EVA module design considerations.

5.2.11.7 Interface Considerations - All of the interfaces identified for this item were considered to be the same or very similar to those interfaces developed and flight qualified during the Skylab program. Thus, no new technology items were identified in this area. A typical sample of envisioned interfaces are as follows:

EVA Module/Habitability Facility

EVA Module/Airlock

EVA Module/Cherry Picker

Fluid Interfaces: Oxygen, Electrical Power, H₂O, etc.

5.2.11.8 Development Plan - The future activities recommended as a result of the conclusions reached in this preliminary evaluation are summarized below and on Figure 5.2.11-2.

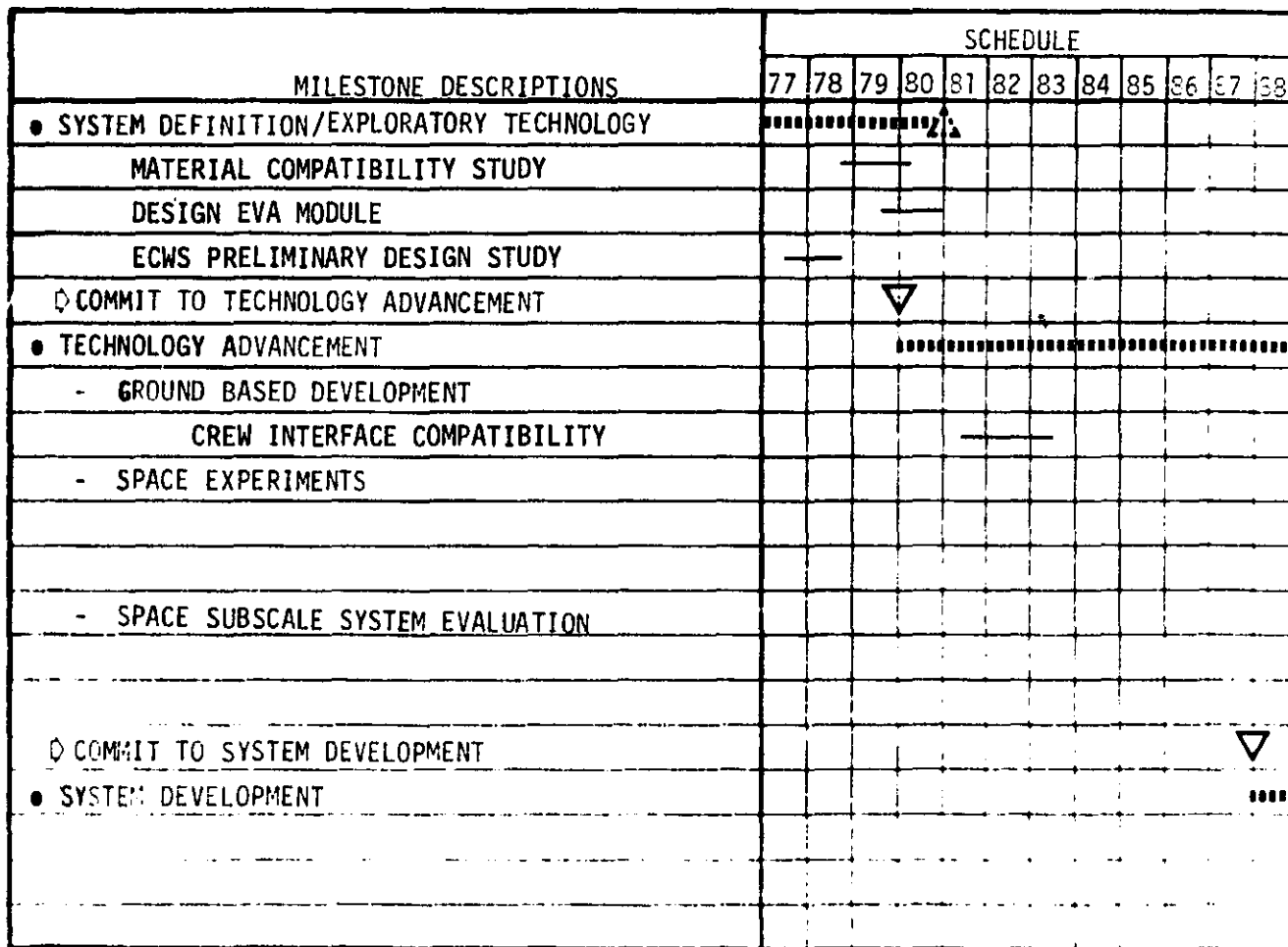


Figure 5.2.11-2 EVA Module Development Schedule

5.3 OCSE System Considerations and Interrelationships

In addition to identify the major design requirements of the 11 items of OCSE, it is important to consider the areas of commonality among the separate OCSE elements and in SPS operations, and to identify areas of overlapping technology across the OCSE spectrum. Although each item of OCSE requires a unique design and development cycle, in programmatic terms all items of OCSE are related to each other and to the SPS development cycle.

Several significant areas of commonality exist within anticipated SPS construction operations, and these factors can impact development of the specific items of OCSE. Table 5.3-1 identifies the construction phases and lists the major areas of commonality which are important to OCSE design and development. The major fabrication process for SPS construction is beam fabrication and joining for the main structure. Several items of OCSE are required to support beam fabricator transport, alignment and mounting at the work site, and resupply. Although the range of SPS element configurations is large, many of the items exhibit similar mass properties. The application of OCSE during the initial phase of SPS setup may be quite extensive. Potential sequences for such operations all require the same types of support. The basic construction tasks beyond fabrication include assembly, handling of structural elements or modular packages, docking, monitoring and checkout. Items of OCSE are required for each of these activities. Finally, access to the individual work sites, whether internal or external to existing structure, is critical to all aspects of support--transport, handling, docking, maintenance tasks, crew schedules, and timelines are all dependent on the methods utilized to travel around the construction base and the SPS itself.

The technology required to accomplish the tasks defined for the 11 items of OCSE is extensive. It is significant to note, however, that these technology areas overlap across the spectrum of OCSE items. Table 5.3-2 shows this overlap in 17 separate technology areas for the 11 OCSE items. Although a specific technology might apply to most of the OCSE items, there may exist several levels of study within the applicable group. For example, the interplay among such OCSE as manipulators, long boom, cherry picker, and structure-attached transporter is illustrated in Table 5.3-3. These items might then

Table 5.3-1 Areas of Commonality in SPS Construction Affecting OCSE Design

CONSTRUCTION PHASES

- Set up, starting the SPS construction;
- Construction;
- Operational checkout;
- Construction items removal;
- Operational;
- Maintenance and Repair

COMMONALITY

- Basic fabrication of structural elements;
- SPS element configurations--mass, size, c.g., etc;
- Sequence for the first SPS setup;
- Construction tasks work elements;
- Access to work site (external vs internal to existing structure)

be considered in concert for particular technology areas such as control modes, capability to interface with multiple systems, mechanical attachment interfaces, and mobility requirements. Such potential interrelations are summarized in Table 5.3-4. These systems considerations and interrelationships, together with the programmatic associated with applications of OCSE to pilot plants (see Section 5.4 following), influence the development schedules to be defined for each item of OCSE. These schedules are presented in the following section of this report.

Table 5.3-2 Overlapping Technology Areas for OCSE

OCSE	OVERLAPPING TECHNOLOGY AREAS																	
	Manipulators	Alignment	Docking	Thermal Control	Vehicle/Track Interfaces	Life Support Provisions	Handling and Positioning Required	Stabilization and Control	Communication	Handling and Berthing of Unit	Remote Manned Control	Autonomous Control	Hybrid Control System	Mechanical Connectors	Fluid Connectors/Fluid Tight Joints	Fluid Leak Detection and Repair	Electrical Connectors	Commodity Servicing
● Manipulator, fixed or mobile base, or dual, ≥ 5 DOF	X	X		X	X		X		X	X	X	X	X	X			X	
● Docking device for joining large systems	X	X	X	X			X		X	X	X	X	X		X		X	
● Manned Cherry Picker, attached to boom or structure	X	X	X	X	X	X	X		X	X				X	X	X	X	X
● CHAD Module	X	X		X		X		X					X				X	X
● Fixed-base Boom, long/extendable, ≤ 4 DOF	X	X		X					X	X	X	X	X	X			X	
● Maintenance Repair Module	X	X	X	X		X	X		X	X	X			X	X	X	X	X
● Commodities Storage Module	X	X	X	X				X	X		X	X	X		X	X	X	X
● Personnel/Material Transporter, structure attached	X	X		X	X	X	X		X	X				X	X	X	X	X
● OCSE Storage Panels	X	X	X				X		X	X	X	X		X			X	
● Personnel/Material Transporter, free-flying	X	X	X	X	X	X	X	X	X	X				X	X	X	X	X
● EVA Module		X	X	X		X	X		X	X					X	X	X	X

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Table 5.3-3 Factors Influencing Technology Overlap for OCSE

FACTOR	OCSE	Manipulators	Docking	Cherry Picker	CHAD Module	Booms	MRM	CSF	Structure Attached Transporter	Storage Panels	Free Flying Transporter	EVA Module
Required Or Desired In The Early SPS Phases e.g. Pilot Plants		X		X	X	X			X		X	
Applicable To All Present Or Potential SPS Configurations		X	X	X	X	X	X	X	X	X	X	X
Covers A Number Of Technology Rqmt. Areas That Other OCSE Also Need		X	X	X		X	X	X	X	X	X	
Adequate Technology Requirements And Definition Exists At This Time For Meaningful Investigation Design And Test Phases (Don't Want White Elephant)		X	X	X		X			X		X	
I-G "Man-In-The-Loop" Simulations Required To Establish Or Evaluate Design Parameters		X		X		X			X			X
Work In This OCSE Arena Will Complement Presently Ongoing Studies (e.g. ECWS)		X	X	X	X	X	X	X	X		X	X
Time Phasing Must Be Studied Early As It Has Impact Upon Or Critical Interrelationship With Other SPS System Designs Such As Construction Eqt., SPS Configuration, Jigs Req'd, Etc.		X			X	X			X			

Strong Interplay
Among These OCSE Items

MARTIN MARETTA

Table 5.3-4 Examples of Interplay Among OCSE Items

MANIPULATOR, FIXED OR MOBILE BASE vs LONG BOOMS

- Lengths, degrees of freedom, control modes all related
- Each can interface with multiple systems (cherry picker, ECWS, structure-attached transporter)

CHERRY PICKER vs MANIPULATOR/BOOM

- Cherry picker can be positioned by boom or manipulator
- Control interfaces similar

STRUCTURE-ATTACHED TRANSPORTER vs CHERRY PICKER

- Cherry picker can travel on structure, interfaces similar
- Transporter can position cherry picker

STRUCTURE-ATTACHED TRANSPORTER vs LONG BOOM

- Transporter can travel over boom
- Boom can form interface between cherry picker and transporter

5.4 OCSE Applications to Early Space Structures Development

5.4.1 Proposed Development and Verification Programs

The requirements for large space structures have generated preliminary plans for numerous space verifications of equipments and procedures during the 1981-1987 time frame. Some of these planned activities are presented in Table 5.4.1-1.

Table 5.4.1-1 Preliminary Plans for Large Space Structures (1981-1987)

EVENT	TIME FRAME	SOURCE
Beam Fabrication Facilities (metal and composites)	1981-1982	NASA RFPs (1977)
Basic Structural Evaluations	1982-1984	NASA RFPs (1977)
Construction Base	1983-1984	NAS8-31993 (GAC)
Solar Power Demonstrations	1984-1990	NAS9-14958 (MDAC) NAS8-31993
Space Manufacturing Facility	1984-1985	NAS8-31993
Public Service Platform	1984 & 1990	NAS8-31993
Teleoperator Space Spider Demonstration	1985	NASA RFP (1977)
Deployment of Large Structures in Space	1982-1987	SAMSO RFP (1977)

A review of the structural assembly requirements shows a number of common equipments required to accomplish these space construction tasks. Functional analyses of these tasks have identified the manipulators, manned cherry pickers, CHAD modules, personnel/material transporters, and commodities storage modules as being basic OCSE items for these operations, and that these equipments would be used in the same roles and configurations for future (1995) construction projects. Other OCSE items such as fixed-base booms, maintenance repair modules, and docking devices (for large systems) would have major roles in very large structural assembly activities in the 1995 era. Then, a few items such as the OCSE storage panels and the EVA module may evolve from relatively simple equipments in the 1985 time frame to more complex items in the 1995 era.

In reviewing various space structures studies, a correlation was developed between the development of the Solar Power Satellite and the development of the OCSE. Many of the different tasks associated with orbital construction demonstration can be satisfied by similar support equipment types as identified for the 1995 era. Based on an early study guideline the McDonnell Douglas Corporation's study on *Space Station Systems Analysis Study*, NAS9-14958, December 1976, was to represent the group of large space structure demonstrations. A result of this study was the recommendation, in the area of SPS support requirements, to start an early SPS demonstration using the pilot plant technique.

The pilot plant concept identified involved the verification/demonstration of the critical subsystems of the Solar Power Satellite (SPS). The verification as presented was divided into four phases:

- a) Shuttle sortie component and subsystem development (1979 - 1980);
- b) Pilot Plan 0 (57 Kw) will be constructed in LEO in mid-1984 to demonstrate assembly techniques and orbital environmental effects. This system will be boosted to GEO to verify orbital-to-ground functions and environmental and transport effects (see Figure 5.4.1-1);
- c) Pilot Plan I (479 Kw) will be constructed in LEO in mid-1985 to demonstrate end-to-end space construction and functions of the SPS, inclusive of large scale energy collection (see Figure 5.4.1-1);
- d) Pilot Plant II (17 Mw) will be constructed in 1990 as a partial prototype of the complete SPS. This unit will then be boosted to GEO (see Figure 5.4.1-2).

The major OCSE identified for an SPS would be demonstrated primarily during the construction of Pilot Plant 0, I, and II. Preliminary evaluations may be performed during Shuttle sortie flights, and data from similar equipments and technology areas would be applied to the OCSE. Therefore, the Pilot Plant II will be considered as an operational project for some of the previously verified OCSE. The OCSE space demonstration will have the primary objectives of demonstrating the following:

- All interface compatibilities;
- Vacuum environment operations;

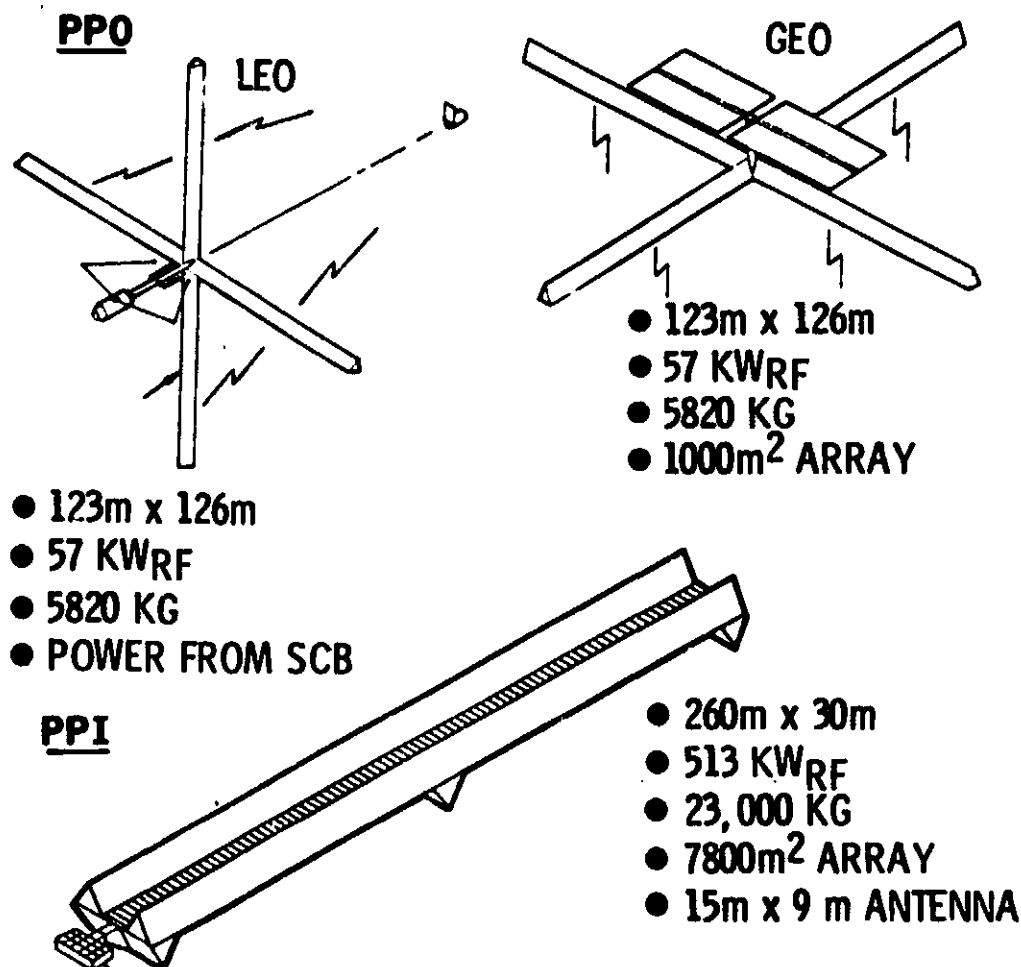
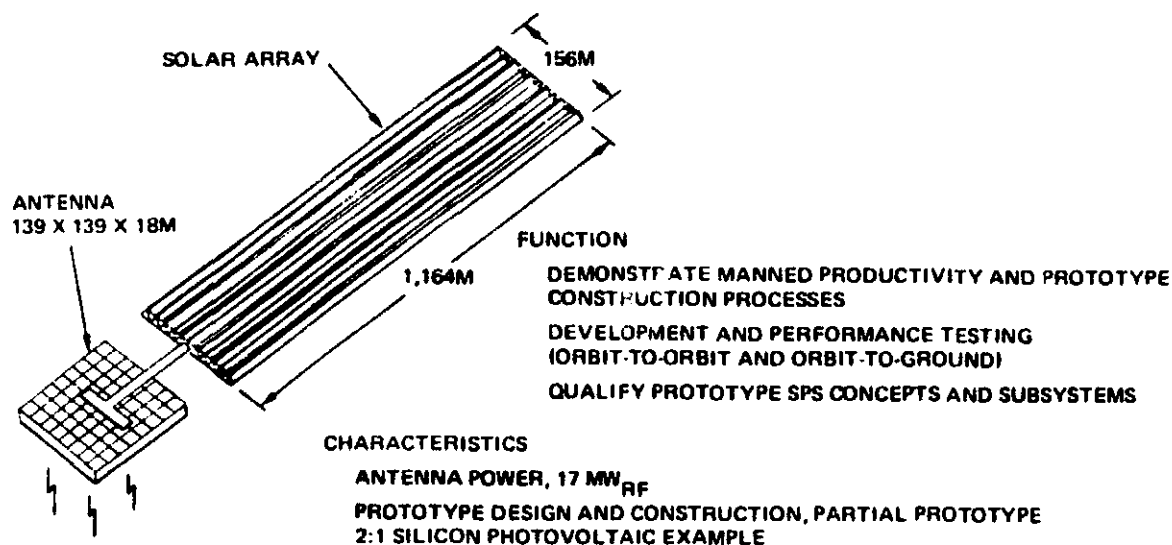


Figure 5.4.1-1 Pilot Plant 0 and I Configurations

- Capability to do useful work;
- Operational timelines and task complexity;
- Man/machine and controlled functions.

Because the OCSE must be capable of sustaining the Shuttle launch environment, the equipment will be structurally capable of significant ground testing. Therefore, operational performance task performance and crew member familiarity (evaluation) can be accomplished prior to flight. In the following paragraphs we present the description of the pilot plants 0 and I from Contract NAS9-14958 (McDonnell Douglas) and the OCSE demonstration/verification interactions. Paragraph 5.4.3 presents a development plan for the various OCSE.



	WEIGHT (1,000 KG)	FLIGHTS
CONSTRUCTION BASE LOGISTICS	64	8
SOLAR ARRAY	60	4
ANTENNA	186	8
	310	20

Figure 5.4.1-2 Pilot Plant II Configuration

5.4.2 Pilot Plant Descriptions

The SPS pilot plant "evolution" process will be conducted over the 1984 - 1991 time frame starting with the basic fabrication, assembly, and checkout of a small power satellite and progressing to prototype of the complete SPS operating in a geosynchronous orbit. Intermediate steps will include microwave transmission, GEO-to-ground operations, LEO and GEO transport and environmental effects, and large scale energy collection processes.

The Pilot Plant 0 (PPO) is a small power station (57 Kw) that will demonstrate some of the most basic SPS technology areas of structure fabrication and assembly, microwave power transmission, and beam mapping. It is proposed by McDonnell Douglas that this assembly be a cruciform configuration with each of the four legs being an open truss structure with a

length of approximately 60 meters. The trusses would be fabricated from a beam builder and positioned at a power and propulsion module by a long manipulator arm. A wire harness/power bus assembly and the antenna panels would be installed on the cruciform legs by EVA from a manned cherry picker attached to a second long manipulator.

After completion of testing in low earth orbit, the PPO facility will be boosted to GEO, using an Interim Upper Stage (IUS) booster. This phase of operation will demonstrate transport loading, GEO-to-ground operations/controls, and environmental effects.

The Pilot Plant I (PPI) is a 479 Kw system that was sized for the maximum power density subarray based on the prototype Solar Power Satellite. In addition to the large scale solar collection and energy conversion technology areas, PPI will be the system end-to-end functional verification of the prototype SPS. The construction process that is suggested by McDonnell Douglas involves construction of the 9.0 x 14.4 x 3.3 meter antenna using the same general sequences and equipments as used on PPO. Then the solar array is constructed using a construction facility that generates the 260 x 30 x 17 meter continuous open truss structure. The solar cell blankets and reflectors are continuously unrolled and attached to the structure as it is generated.

The construction facility is basically a structural frame to which six beam cap roll forming machines are rigidly attached. Industrial robots are attached for the positioning and attaching of lateral support struts. The rolls of solar cells and reflectors are also supported by this structural frame. The role of OCSE is essentially the same as that required for the PPO, but the PPI construction activities will require more versatility and mobility.

The system study for the PPII (17 Mw) was not available at the time of this OCSE study. However, the existing McDonnell Douglas data are sufficient to illustrate the means to both verify and demonstrate OCSE. It has become apparent that the flight verifications of the OCSE can be time-phased with the demonstration of the pilot plants, where equipment complexities are demonstrated during the construction/assembly project prior to the project at which it is required. Therefore, the Shuttle sortie flights of 1980 - 1984 would be used to verify OCSE functions that are required for

PPO; OCSE functions would be verified on PPO (after completion of the primary tasks) for the construction tasks of PPI; This philosophy will ensure there is adequate time between construction phases for refinements, corrective actions, and final crew evaluations/verifications. Furthermore, this test phasing will provide assurance that the OCSE will be adequately demonstrated in order to provide full capability for the prototype Solar Power Satellite.

An evaluation of the equipment typed required to support the pilot plants has identified that the initial pilot plant (PPO) as proposed by McDonnell Douglas would require two long manipulators, a manned cherry picker, a habitable core module, and a maneuverable satellite. From this type of data, the information Table 5.4.2-2 was generated which presents a priority for the development of the various OCSE.

Table 5.4.2-2 Priority of OCSE Development

OCSE	1984	1985	1986	1987	1988	1989 & BEYOND
Manipulator (fixed or mobile base)	X					
Docking Device (for large systems)		X				X
Manned Cherry Picker (boom or structure attached)	X					
CHAD Module	X					
Fixed-base Long Boom						X
Maintenance Repair Module				X		
Commodities Storage Module			X			
Personnel/Material Transporter (structure attached)						X
OCSE Storage Panels		X		X		X
Personnel/Material Transporter (free-flying)		X				
EVA Module		X		X		X

Each of the OCSE items shown on this table have been identified with specific roles which relate to the pilot plant evolution.

5.4.3 OCSE Development Plan

The OCSE development will be consistent with other aerospace hardware development programs. However, early hardware development should make use of the NASA protoflight concept of early flight testing of subsystems to reduce the number of test hardware units, reduce the extent of ground testing, and make use of the Shuttle to return hardware for post-test inspections and analyses. With this programmatic philosophy all subsystems will be divided into manned and unmanned elements where the manned elements such as the manned cherry picker, the personnel/material transporter, and the EVA module will receive more extensive ground testing to demonstrate flight worthiness. Considerations must include commonality of design for the numerous manned capsules as a method to reduce total program costs. As an example, it is likely that the pressurized capsules, airlocks, consumables feed-through interfaces can be one common design for the four manned OCSE items.

The unmanned elements such as the manipulators, booms, docking devices, and repair and storage modules can be initially evaluated from the Orbiter payload specialist station with the elements being captive within the cargo bay. The Shuttle remote manipulator system and EVA would augment these evaluations.

After completion of the subsystem tests, the elements can be assembled and ground tested to verify all interfaces. The OCSE would then be functionally verified as a system, as cost-sharing payloads during the Shuttle sortie flights, using task panels and structure mockups for operational simulations. This verification process will ensure the operational demonstration, as part of the pilot plant construction, can be performed efficiently.

An OCSE development and demonstration plan is presented in Figure 5.4.3-1. This plan is typical for each of the OCSE hardware items, although there is a strong likelihood that subsystem commonality will be identified during the initial design study. There are five primary phases to the development/

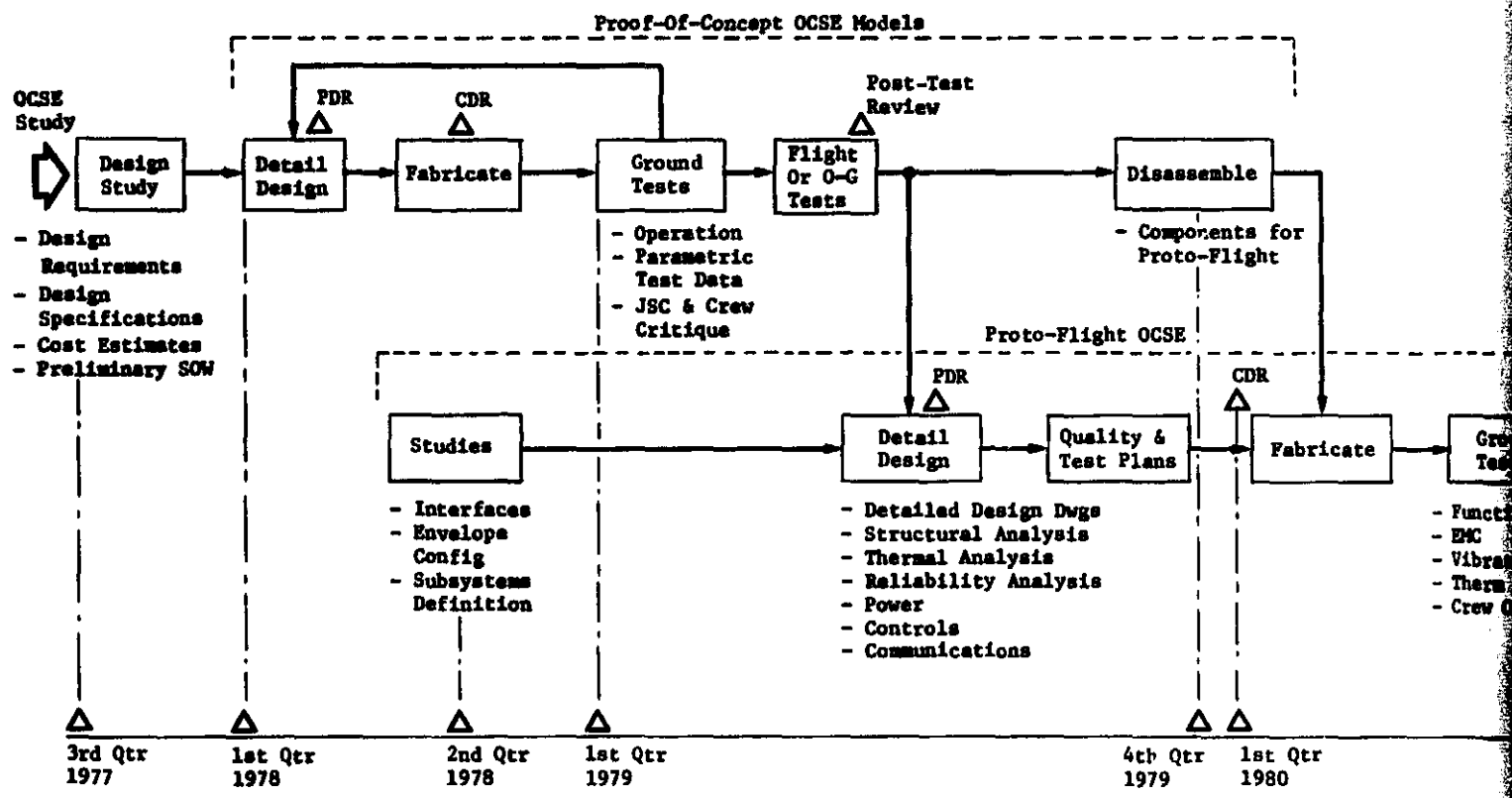


Figure 5.4.

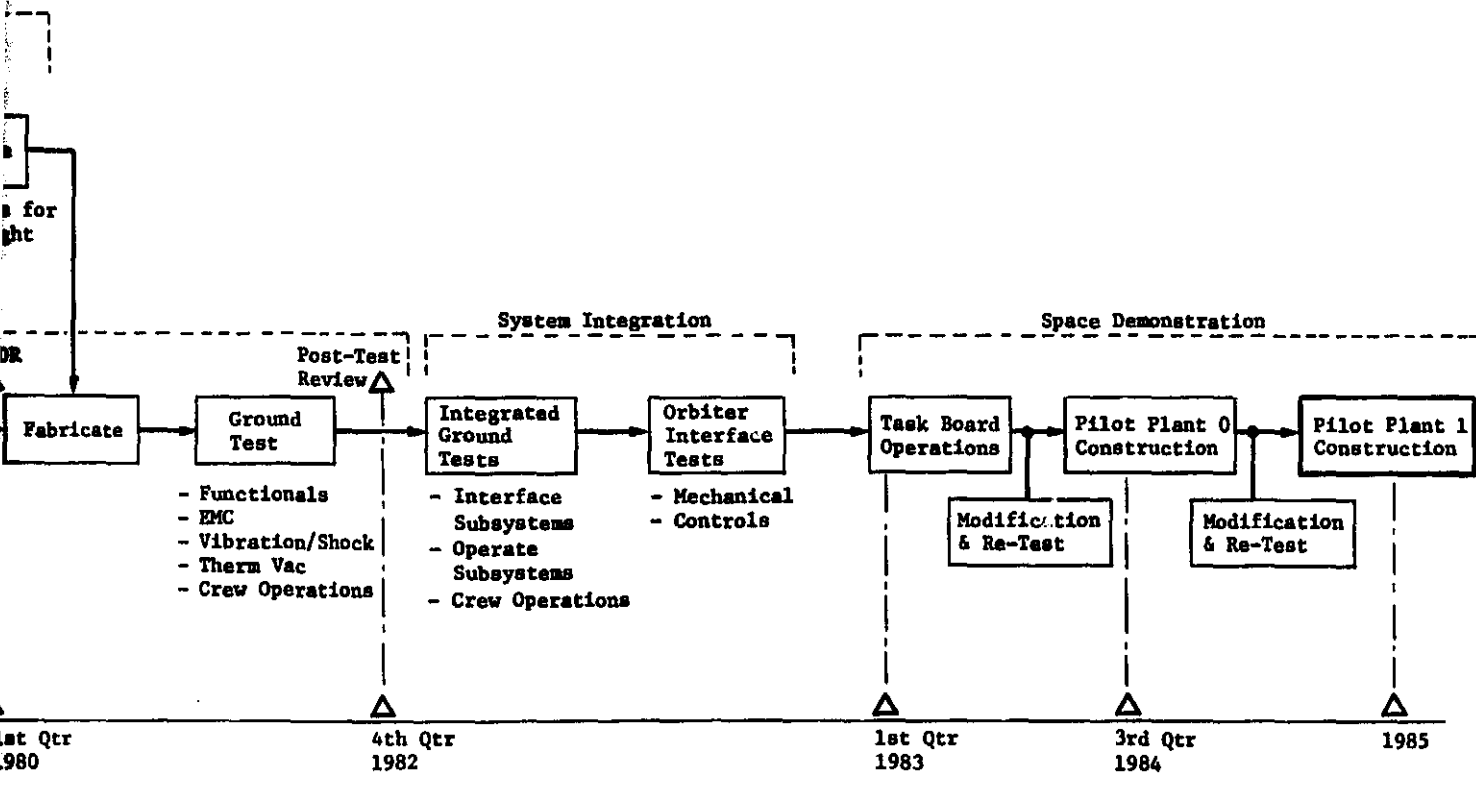


Figure 5.4.3-1 Orbital Construction Support Equipment Development and Demonstration Program

demonstration: 1) design study; 2) proof of concept OCSE models; 3) proto-flight OCSE; 4) system integration; and 5) space demonstration. Each of these phases are discussed in detail in the subsequent paragraphs.

5.4.3.1 Design Study - The OCSE design study will be conducted over a period of nine months in order to generate the design requirements and specifications for the various OCSE items. A significant portion of the design specifications related to product configuration, useful life, environmental requirements, quality assurance provisions, and delivery requirements will be very similar or identical for each equipment. Based on the design requirements, common capsules for manned operations would be identified. Other outputs of this study would include a program statement of work, a work breakdown structure (WBS), and preliminary cost estimates for the balance of the OCSE development and demonstration program.

5.4.3.2 Proof of Concept OCSE Models - This phase is planned for a period of 24 months in order to develop the preliminary designs for the numerous hardware items that are categorized as OCSE. Proof of concept hardware will be fabricated and tested where preliminary evaluations are required. In the cases where scaled models will be cost effective as design/test aids, they will be considered. This phase will also make use of the vast design experience from the NASA manned space projects, particularly Apollo and Skylab, as well as the STS. Off-the-shelf components will be used in most cases to ensure a cost-effective design development phase. Although materials and processes may not be flightworthy, the space and Shuttle compatible materials will be identified during this phase. Manufacturing will be conducted in close liaison with design personnel to reduce design change turnaround. The test activities will provide basic parametric data such as weight, power, volume, operating rates, and efficiencies. Zero gravity tests may be performed using the NASA low gravity aircraft or early Shuttle flights, if equipments are compatible. Where applicable, some of the proof-of-concept hardware would be disassembled from the equipment and used in the protoflight phase of the program.

In addition to program progress meetings, it is recommended that three formal reviews be conducted:

- Preliminary Design Review - This review will present the preliminary OCSE designs and identify how the design requirements and specifications are being met.
- Critical Design Review - This review will present the detailed design of the OCSE items and supporting analyses for NASA approval prior to the start of manufacturing.
- Post Test Review - This review will present the results of the proof of concept tests, the anomalies and corrective actions. Considerations will be presented for the test planning of the protoflight phase of the program.

5.4.3.3 Protoflight OCSE - This phase is planned as a 54-month period of performance, basically subdivided into 18 months for design and studies, 18 months for manufacturing, and 18 months for ground testing. The studies in support of this phase will primarily produce the interface control documents related to the Orbiter and the construction equipment, the stowage and deployed envelopes for the OCSE, and the definitions of the OCSE subsystems. The detailed design activity will produce flight-type engineering drawings supported by structural and thermal analyses, and failure modes and effects analysis. Subsystems to include power, controls, communications as defined from the previous study will be designed for each of the OCSE items. The designs must consider common usage hardware, serviceability, and maintainability due to the projected missions for these equipments. Because of the flightworthy and man-rated criteria for the OCSE, formal quality assurance and test plans will be developed for controlling the hardware items. Plans will be submitted for NASA approval, and a process for reporting anomalies and thorough corrective actions will be mutually agreed upon. The OCSE will be fabricated from materials and with processes that have been certified as being flightworthy and compatible with the space and Orbiter environments. Formal quality assurance and engineering change controls will be imposed to ensure hardware configurations are consistent. Component procurement will require the same flight hardware standards.

Ground testing will be performed to verify the integrity of each OCSE item. The testing would include electromagnetic compatibility (EMC), vibration and shock, and thermal-vacuum environments with functional operations

during the thermal-vacuum tests and before and after each environment. Crew member operations will also be included.

In addition to regularly scheduled program meetings, formal reviews to include a PDR, a CDR, and Post Test Review will serve the functions as previously described in paragraph 5.4.3.2.

5.4.3.4 System Integration - This phase of the program will be three to six months duration depending on Shuttle launch schedules and availability of cargo bay space. During this period the specific OCSE hardware items will be integrated with all associated subsystems and a system end-to-end verification accomplished. The flight readiness review will be conducted to ensure all related program activities have been successfully completed and that no open action items exist.

The OCSE item and supporting subsystems will be stowed in the Orbiter cargo bay, verifying the integrity of all interfaces. In the case of the Shuttle sortie flights for initial task board operational verification of the OCSE, the Orbiter payload specialist station controls will be installed and functionally verified as well.

5.4.3.5 Space Demonstration - We have identified the first three space demonstrations as: 1) task board operations; 2) pilot plant 0; and 3) pilot plant I. It is our estimate that a major amount of activity will take place in 1983 - 1984 time frame to accomplish the necessary space verifications of each of the OCSE items. The availability of the more complex equipments must be scheduled to permit adequate test/verification time.

A point of reference for space demonstration span times is the Apollo Command Module/Lunar Module docking interface. In the case of the OCSE, many of the hardware items will be of comparable complexity and therefore adequate schedules must be provided. Our program plan also identifies a task for modification and retest between space demonstrations.

By the time that Pilot Plant 0 is ready for construction, several OCSE items must be operational, including the base core module, the manipulator, and the cherry picker. Typical items and activities that could be demonstrated during these demonstration phases include the following:

Manipulator Arms - The manipulator arms are required to accomplish the positioning of the structure elements including the beams, antenna panels, etc and the maneuvering of the manned cherry picker.

Manned Cherry Picker - The cherry picker provides a semi-mobile platform with teleoperator subsystems for the crew member while in the immediate vicinity of the fabrication and assembly areas. Initially, the cherry picker may be unpressurized, but a pressurized habitable capsule should be considered in conjunction with the personnel/material transporters.

CHAD Module - The CHAD module, to which the manipulators are attached, is visualized as the primary operating base for orbital construction, furnishing power, communications, and a control system. This module will probably be remotely controlled, but some manned, pressurized concepts can also be envisioned.

Docking Device (for large systems) - The docking device will permit the joining of large structures, such as would be required for LEO fabrication and subassembly requirements are identified for the pilot plants, such as joining two legs of the cruciform on PP0. Of course, other techniques such as those presently being studied under structural assembly contracts, are also applicable.

Personnel/Material Transporter (free-flying) - This transporter may be a large manned maneuvering unit, which has a pressurized capsule (such as the cherry picker) for shirt-sleeve operations. Small manipulators and a CCTV and lighting system are part of this equipment. Specifically, the transporter would be required to resupply rolls of solar cells from the Orbiter cargo bay to the PP1 construction facility.

Personnel/Material Transporter (structure attached) - This transporter would be an adaptation of the free-flying transporter having a special chassis that adapts to the fabricated structure or to the structure geometry of the fixed-base long boom. This transporter would not require development until very large structures are being planned (1995 era).

Fixed-base Boom - This boom is visualized as an extended capability of the manipulator arms that are required for the pilot plant construction. Therefore, the fixed-base boom development would not be required until the 1995 era.

Maintenance Repair Module - This module would be used on very large structures to accomplish repairs such as replacement of faulty components/equipment, support structure replacement, remove/replace solar cells, etc. The module should include compaction/scrap storage equipment to reduce space debris.

Commodities Storage Module - This module would be used with the very large structure configurations where orbital resupply of commodities is required. Consequently, there is a need for providing supply depots, refueling stations, etc. Due to the materials or fuel types, the locations and procedures used to provide the storage and resupply functions must be accomplished with minimum risk to personnel and equipment involved.

5.5 Recommended OCSE

This section covers the final OCSE evaluation and preference ranking of the 11 items remaining from the preliminary OCSE concepts screening task. The prime objective of this effort was to present a recommendation for a representative piece of OCSE with supporting rationale for a follow-on effort leading to its design, fabrication, and development testing. To accomplish this an approach was developed which generated recommendation criteria based on future SPS program desires. Using these criteria a trade-off evaluation was prepared among the 11 candidate OCSE items in order to identify a trend in ranking of development preference.

5.5.1 Recommendation Criteria

The objective of this subtask was to develop the criteria necessary to show the rationale for making a final concept recommendation. The approach used was to take the OCSE screening criteria developed in section 4.3.1 and expand them to include some additional parameters which obviously required more detailed evaluation.

Many different tradeoff parameters were reviewed which could have an impact on ranking positions. Some of these were eliminated due to having insufficient comparison data or minor impacts on the final ranking position. However, some were retained to show the level to which the evaluation data was developed. This also resulted in a narrowing down of areas where future analyses with the greatest impact on new development decisions should be directed. The parameters used in the final comparison evaluation are:

1) Pilot Plant Applications - Does the support equipment identified for Pilot Plant fabrication and assembly satisfy the physical and functional requirements projected for the 1995 Solar Power Satellite construction era? The OCSE identified with PP activities should be started first.

2) SRT Development Status - Are the SRT efforts identified with the logical development of the OCSE items included in NASA planning? The SRT areas identified which are not already part of ongoing studies should have a high preference for near term development.

3) Costs - Cost data used in decisions on OCSE development should be based on the lowest cost first. Cost data should include all program areas; i.e., flight hardware, ancillary equipment, and supporting services required to fully integrate each concept into unified operational programs. However, cost data to this level are not always available and may not warrant the additional time to develop them.

4) Benefits - When making the decision on whether to start a new development, the potential cost benefits in relation to program costs is one of the most important decision factors.

5) Risk Considerations - The general risk analyses investigate and identify the uncertainties that could significantly affect performance, cost, and schedule and define provisions to minimize technical and cost risks.

6) Crew Safety - The entire process of crew activity, shifts, rotations, timeoff, recreation, transportation, etc involves much uncertainty. Any OCSE which provides some form of crew safety should be considered an advantage to future planning.

7) Crew Productivity - Since the number of orbital construction personnel have been identified in related studies, the impact which OCSE has on crew productivity must be considered. The OCSE which has a greater impact on increasing crew productivity is desirable.

8) Preliminary Screening Rank - This includes the compiled ranking results from the preliminary screening task which compared 12 parameters (see Section 4.3).

5.5.2 Concept Development Preference Ranking Process

The OCSE concept preference ranking process used here was based on a simple summary method. The emphasis during this part of the task was to compare each concept against each of the selected parameters. Due to the coarseness and in some areas lack of comparison data, the results of this specific effort are intended to show trends rather than exact conclusions. The approach used to accomplish the final preference ranking depended on a combination of evaluation procedures which looked at data from related studies, study derived data, initial guidelines and on the experience and

judgment of the study participants. A simple prioritization process was used which aided in separating the preferred characteristics, from the most preferred (assigned one) to the least preferred (assigned eleven) when compared against each other. Table 5.5.2-1 shows the 11 OCSE items compared with each of the eight evaluation parameters. A final ranking is presented which is a numerical tally of all the individual rankings with the lowest value having the highest preference. This was considered a very simplistic approach in that no weighting factors were applied. Each of the eight preference ranking parameters carried the same weighting factors, although different weights might be applied. For example, the pilot plant application parameter could have a weighting factor of three times the risk considerations. The methodology and data source used to make this comparative evaluation is presented in Table 5.2.2-2.

Additional rationale for making the final preference ranking is presented in the conclusions and recommendations.

Table 5.5.2-1 OCSE Development Preference

PRELIMINARY SCREENING GROUP	PRIORITY RANKING CRITERIA								
	PRELIMINARY SCREENING PRIORITY RANKING	PILOT PLANT APPLICATION	SRT & DEVELOPMENT STUDIES	CREW SAFETY	CREW PRODUCTIVITY	COSTS	RISK CONSIDERATIONS	BENEFITS	FINAL RANKING
Manipulators (fixed base)	1	2	6	8	2	9	2	5	3
Joining Large Systems	2	4	2	6	9	2	1	6	2
Cherry Picker	3	2	5	1	3	3	4	7	1
CHAD Module	4	3	4	2	8	11	5	1	4
Booms Fixed Base	4	3	4	2	8	11	5	1	4
Maintenance Repair Module	6	9	8	10	7	8	8	2	8
Commodities Storage	7	8	7	5	10	5	10	3	6
P&M Transporter, Structure Attached	8	11	2	4	5	6	9	10	7
OCSE Storage Panels	9	5	11	11	11	1	11	11	11
P&M Transporter, Free Flying	10	6	10	3	4	7	7	9	9
EVA Module	11	7	9	9	6	4	6	8	10

Table 5.5.2-2 Comparative Evaluation Methodology

RANKING CRITERIA	COMPARATIVE DATA SOURCE
Preliminary Screening Ranking	Used ranking data developed in section 4.3.
Pilot Plant Application	Assigned ranking based on operational need requirements derived in section 5.4.
SRT & Development Status	Rankings based on comparative review of SRT requirements vs known SRT studies.
Crew Safety	Rankings based on experience and judgment of study participants.
Crew Productivity	Rankings based on experience and judgment of study participants.
Costs	Cost estimates developed for project DDT&E and production used from lowest (1) to highest (11).
Risk Considerations	Rankings based on experience and judgment of study participants.
Benefits	Rankings based on experience and judgment of study participants.

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- c) *AIAA/MSFC Symposium on Space Industrialization, Proceedings, May 1976.*
- d) *Industry Workshop on Large Space Structures, NAS1-12436, NASA CR-144997, May 1976, NASA/LARC.*
- e) *A Forecast of Space Technology, 1980 - 2000, NASA SP-137, January 1976.*
- f) *Outlook for Space, Report to the NASA Administrator by the Space Study Group, NASA SP-136, January 1976.*

6.1.9 National Academy of Sciences

- a) *Radiation Protection Guides and Constraints for Space Missions and Vehicle-Design Studies Involving Nuclear Systems, NAS-NRC, Washington, D. C., 1970 (except Appendices).*

6.1.10 Rockwell, Downey, California

- a) *Study to Determine Extravehicular Mobility Unit (EMU) Advanced Technology Requirements, Volume II, Technical Analysis, Contract NAS2-8957, May 1976.*

- b) *Study to Evaluate the Effects of EVA on Payload Systems, Volume II, Technical Analysis, Contract NAS2-8429, November 1975.*
- c) *Concept Definition and Systems Analysis Study for a Solar Electric Propulsion Stage, NAS8-30920, January 1975.*

6.1.11 Raytheon

- a) *Microwave Power Transmission System Studies, NAS3-17835*

6.1.12 Martin Marietta Corporation, Denver, Colorado

- a) *Manned Maneuvering Unit System Design Specification, NAS9-14593, April 1976.*
- b) *Earth Orbital Teleoperator Systems Concepts and Analysis, NAS8-31290, Volumes I, II, and III, May 1976.*
- c) *Integrated Orbital Servicing Study for Low-Cost Payload Programs, NAS8-30820, September 1975.*
- d) *Orbital Assembly and Maintenance Study, NAS9-14319, Technical Report, August 1975.*

6.2 Abbreviations and Acronyms

ACS	- attitude control system
AM	- airlock module
ASTP	- Apollo-Soyuz Test Project
ATM	- Apollo telescope mount
BT	- Boeing Thermal Engine SPS concept
C/C	- Column/Cable SPS concept
CDR	- Critical Design Review
CE	- Construction equipment
CF	- construction facility
CHAD	- Central hub assembly/deployment
COTV	- Cargo orbital transfer vehicle
CRPM	- Crew rotation passenger module
CSF	- Commodities storage facility
DOF	- Degrees of freedom
ECLSS	- Environmental control life support system
ECWS	- Extravehicular crewman work station
EE	- end effector
EMC	- Electromagnetic compatibility
EMU	- Extravehicular mobility unit
EOTS	- Earth orbital teleoperator system
EVA	- Extravehicular activity
FF	- Free flyer, free flying
FSS	- Flight support system
GEO	- Geosynchronous earth orbit
G,N&C	- guidance, navigation and control
GSE	- Ground support equipment
HLLV	- Heavy lift launch vehicle
IMF	- Integration Management Facility
IOSS	- Integrated Orbital Servicing Study
IUS	- Interim Upper Stage
IVA	- Intravehicular activity
LAD	- Linear assembler/deployer
LEO	- Low earth orbit

LF	- Logistics Facility
LRU	- line replaceable unit
MDA	- multiple docking adapter
MF	- manufacturing facility
MMU	- Manned maneuvering unit
MPD	- magnetoplasmdynamic
MPTS	- Microwave power transmission system
MRM	- Maintenance/repair module
MS	- Maneuvering system
MTV, MTS	- maneuverable television system
N	- newtons
OCE	- Orbital construction equipment
OCSE	- Orbital construction support equipment
OTV	- Orbital transfer vehicle
PCS	- Power conversion system
PDR	- Preliminary Design Review
P-FMA	- Protoflight manipulator arm
PGA	- pressurized garment assembly
PLSS	- Portable life support system
P&M	- Personnel and material
POTV	- Personnel orbital transfer vehicle
PP	- Pilot Plant
RCS	- Reaction control system
REM	- Roetgen equivalent in man
RF	- radio frequency
RTA	- rotary transformer assembly
SC	- Solar concentrator
S/C	- spacecraft
SECS	- Solar energy collection system
SLR	- scanning laser radar
SPDL	- Solar power development laboratory, power plant
SPS	- Solar Power Satellite
SRMS	- Shuttle Remote manipulator system
SRT	- Supporting research and technology
STAD	- Sequential traveling assembler/deployer

STS	- Shuttle Transportation System
T, TT	- Truss configuration SPs concept
TOS	- teleoperator system

APPENDIX A
OCSE REQUIREMENTS DEFINITION SHEETS
OCSE CONCEPT SUMMARY SHEETS

NOTE: The requirements definition sheets and summary sheets which follow are cross-referenced to the OCSE inventory tree (Figure 4.2.1-1, page IV-3) by number and category. The number refers to one of the ten classes of OCSE as defined below, and in Section 4.0. The category refers to the

<u>OCSE Inventory No.</u>	<u>Class</u>
1	Free-Flying Transporters
2	Structure Attached Transporters
3	Handlers
4	Aligners
5	Material Fasteners
6	Adjustment Devices
7	Checkout
8	Monitor Devices
9	OCSE Support Equipment
10	Base Modules

state of development of particular OCSE concepts (on summary sheets), as listed below:

Category A - Flight Existing
Category B - Flight Proposed
Category C - Commercial (One "G")
Category D - New Concept

OCSE REQUIREMENTS DEFINITION SHEET

OCSE INVENTORY NO. 1.0

OCSE CLASS: Free Flying Transporters

OCSE SUBCLASS: Personnel and Materials Transporters

TASK DESCRIPTION: Man-rated cargo transporter; functional equivalent of separate personnel and material transporters with combined capabilities.. (See applicable SUBCLASS sheets.) Carry material (up to 7×10^5 kg, 3000 m³) or personnel (1 to 40) up to 21 km (nominal 100 to 260 meters) to construction site or work locations. Must have stationkeeping, docking or temporary attachment (to structure) capability; integral propulsion, guidance and communications systems. Directly or remotely controlled.

APPLICATIONS TO SPS CONSTRUCTION:

Column/Cable (4.1.3.1): Solar cell packages, 21 km @ 48,000 kg/package, 120 packages (10 x 10 x 8 meters each)
Truss (1.2.4): Power distribution harness installers (4) - 163,000 kg each, 2.6 km
Boeing Thermal: Reflector facet repair/adjustment - personnel travel distance 2.7 km

EXISTING/POTENTIAL CONCEPTS:

- (1) POTV/COTV - JSC SPS in-house study concepts
- (2) MMU/MTV - under development

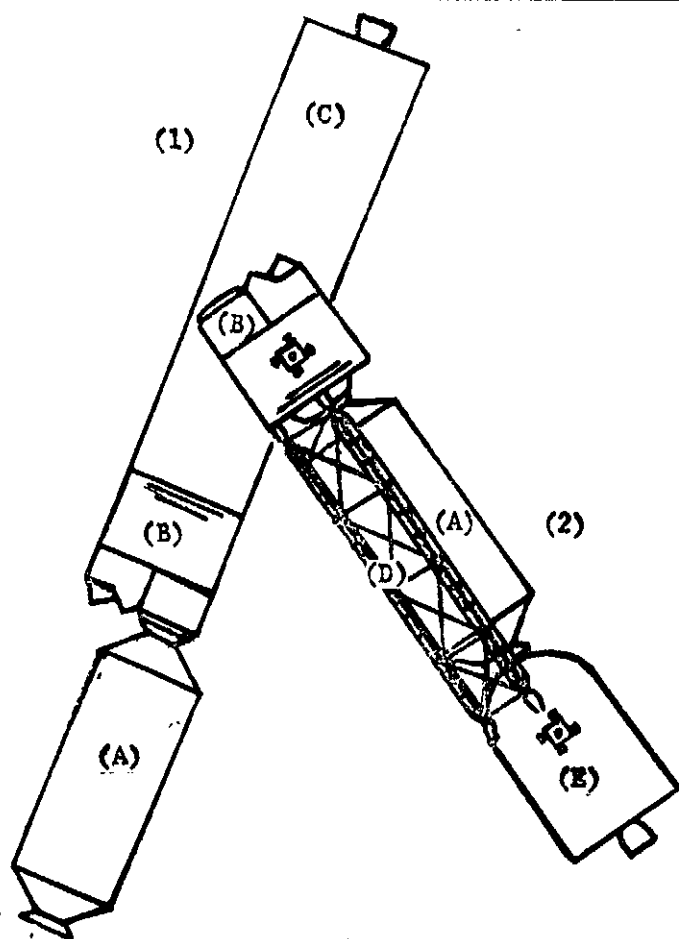
MAJOR INTERFACES: Docking port or temporary attachment mechanism; structure/cable avoidance; must interface with construction equipment or other OCSE at load/unload site; servicing required.

SRT REQUIRED: Covered under related contracts (SPS studies).

SPS IMPACTS: - Traffic control; crew schedules.

OCSE Title: MODULAR FREE FLYING TRANSPORTER

Category B No. 1.1



Data Source:

JSC 11568, Initial Technical, Environmental, and Economic Evaluation of Space Solar Power Concepts, 08-31-76

Operational Description:

Figure (1) shows JSC's concept of a POTV/COTV ((A) personnel module or payload module, (B) crew module, (C) 2nd stage propulsion). Figure (2) shows how crew module, (B), can be linked with a truss, (D), and small propulsion unit (E) to form a general purpose vehicle (shown here carrying a personnel module (A)).

Mass Properties:

Requirements:

Crew: 2 in crew module, up to 20 in personnel module (A).

Environment: Space; crew and personnel modules are pressurized

Service: Putting together modules in MRM

Launch Vehicle: HLLV

Comments:

Truss can be lengthened/shortened for different missions. Several combinations become possible. GP vehicle can be adjusted to compensate for any payload, personnel module, etc.

OCSE REQUIREMENTS DEFINITION SHEET

OCSE INVENTORY NO. 1.0

OCSE CLASS: Free Flying Transporters

OCSE SUBCLASS: Material Transporters

TASK DESCRIPTION: Carry material between locations at or near construction site. Largest package ~700,000 kg mass and 3000 m³ volume; transport distance up to 21 km. Transporter must contain integral propulsion, guidance and communications systems. Docking capability required; cargo restraint system required. Can be directly (pressurized cabin) or remotely controlled; cargo space probably unpressurized.

APPLICATIONS TO SPS CONSTRUCTION: (Typical):

Column/Cable (4.1.3.1) - Solar cell packages, 21 km (travel distance) @ 48000 kg/package, 120 packages (10 x 10 x 8 meters each)

Truss (1.2.4) - Power distribution harness, installers (4 req'd) - 163,000 kg each @ 2600 meters distance max.

Boeing Thermal (2.1.1.1) - Cavity absorber shell (400 pieces @ 53,000 kg each) 20 x 29m panel sections - distance up to 300 meters

EXISTING/POTENTIAL CONCEPTS:

- (1) COTV - JSC SPS in-house study concept
- (2) MMS - under development for Shuttle
- (3) MTV - under development for Shuttle
- (4) EOTS - Phase B Concept

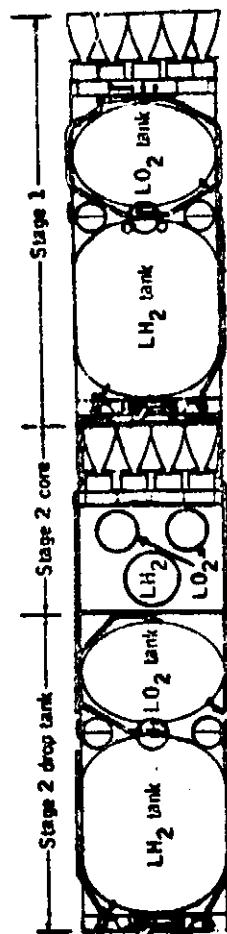
MAJOR INTERFACES: Docking port @ supply depot and @ construction (delivery) site; must interface with construction equipment (solar cell installer, cavity absorber shell assembly jig, etc.) for load/unload; structure avoidance; thruster plume impingement or surface contamination.

SRT REQUIRED: Scale up to large cargo capability; automatic docking techniques

SPS IMPACTS: - Resupply/supply logistics; traffic control

(NOTE: Requirements can also be fulfilled by structure attached transporters; travel distances may increase (non-straight line travel).)

OCSE Title: Cargo Orbit Transfer Vehicle (COTV) Category B No. 1.2



Length: 48 m
Diameter: 8.4 m
Total weight: 510 tons
Propellant weight: 475 tons

2-1/2 stage LO2/LH2
Life: 30 missions
Payload: 250 tons
~910M/ft

Cargo orbital transfer vehicle (COTV_G) characteristics.

Data Source:

JSC 11568, *Initial Technical, Environmental, and Economic Evaluation of Space Solar Power Concepts*, 08-31-76

Operational Description:

The COTV_G is a space-based system designed for transporting from LEO to GEO all the material required for SPS construction or assembly. Two basic COTV systems have been identified, distinguished by whether or not power is available from the payload. The COTV_G designation applies to payloads that cannot provide power for transfer from LEO to GEO.

Mass Properties:

Length: 48m (157.5 ft)
Diameter: 8.4m (27.5 ft)
Total Mass: 510 tons
Propellant Weight: 475 tons

Characteristics:

Functional - Payload: 250 tons

Life: 30 missions

Environment: LEO to GEO and back to LEO

Service (Prop., Elec., Gas, etc) on Orbit (LEO or GEO)

Propellants: LH₂/LO₂

LEO to GEO Transit Time:

Physical -

Docking System Interface: Orbiter, Fabrication Facilities, and SPS Structure or Assemblies

Crew: Unmanned requires automated or remote control

Servicing Interface: Electrical power capability, on-orbit propellant transfer

Power Source: Solar cells

Stages: Two-stage or Two and One-Half Stage options

Comments:

Proposed concept by JSC is in support of the Solar Power Satellite program. Additional reference source is future STS Analysis Study (NAS9-14323).

OCSE Title: Cargo Orbit Transfer Vehicle (COTV) Category B No. 1.3

Data Source:

JSC 11568, *Initial Technical, Environmental, and Economic Evaluation of Space Solar Power Concepts*, 08-31-76

Operational Description:

This COTV designation applies to SPS configurations or payloads that involve construction at LEO, either in total or in modules, which can provide energy for propulsion for orbital transfer. The more attractive thruster systems are those with high specific impulse (ion thrusters).

Mass Properties:

Size: TBD

Mass: TBD

Characteristics:

Functional - Payload:

Environments: LEO to GEO one way transit, with return as option

Propellants: H_2 , Argon, ΔV of 19,685 fps

LEO to GEO Transit Time: 2 to 6 months

Payload (SPS Assy) provides power for propulsion

Physical -

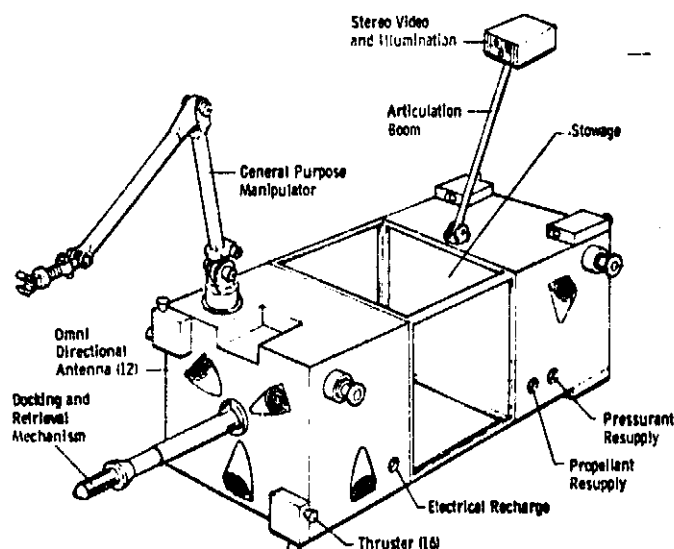
Thrusters: MPD arcjet configuration is best case projection

Crew: Unmanned requires automated or remote control

Interfaces: Electrical power from SPS, attachments to SPS

Comments:

Proposed concept by JSC is in support of the Solar Power Satellite program. Since detailed MPD or ion/argon thruster data are not available, comprehensive and accurate system design is not possible at this time.



Data Source:

*Earth Orbital Teleoperator Systems
Concepts and Analysis, MCR-76-17,
Volume II, Contract NAS8-31290, May 1976*

Operational Description:

Remotely controlled self-contained spacecraft with docking, manipulative, and visual subsystems. Provides remote inspection, module transfer, and miscellaneous assembly operations while under crewman (IVA) control at the construction base.

Mass Properties:

Mass: 318 Kg (wet, 272 (Dry); [700 lb (wet)
600 lb (dry)]
Dimensions: 112x112x193 cm (44x44x76 in.)

Requirements:

Functional -

Missions: Monitor/inspect, deploy/retrieve, satellite service, experiment support, assembly, hazardous material handling, and EVA support.
Docking: Lateral velocity of 0.6 cm/sec; longitudinal velocity 3.0 cm/sec.
Range Limitations: Up to 22 km (12 nm); growth option 120 km (66 nm).
Total Impulse: 20,000 lb-sec, ΔV of 1,000 ft/sec.
Spin/Despin: Spin rates of up to 10.5 rad/sec (100 rpm).

Physical -

Crew: Minimum 1, IVA at EOTS control/display station.
Environments: Space
Service: Propellant resupply; electrical recharge
Launch Vehicle: Compatible with Orbiter, OTV, HLLV, Construction Base
Accept Modules: Weight of 300 kg (660 lb), size of 1 x 1 x 1 meter (3.2 x 3.2 x 3.2 ft)

Comments:

The EOTS may be designed and built by mid-1985 for orbital operations in conjunction with the Orbiter for satellite servicing and retrieval.

OCSE REQUIREMENTS DEFINITION SHEET

OCSE INVENTORY NO. 1.0

OCSE CLASS: Free Flying Transporters

OCSE SUBCLASS: Personnel Transporters

TASK DESCRIPTION: Carry personnel (1 to 40) to construction site, repair site, or between work locations. Maximum range - 21 km, nominal - 100 to 2600 meters. Must have stationkeeping, docking or temporary attachment (to structure) capability; transporter controlled directly (pressurized or unpressurized) and has integral propulsion, guidance and communications systems. Also has rescue applications.

APPLICATIONS TO SPS CONSTRUCTION (Typical):

Boeing Thermal - Reflector facet repair/adjustment - Personnel travel distance ~ 2.7 km

Column/Cable, truss type, MPTS - EVA maintenance/repair, typical travel distances 500 meters to 16 km

EXISTING/POTENTIAL CONCEPTS:

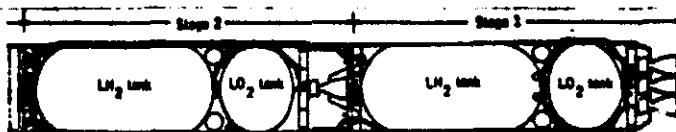
- (1) POTV (20 to 40 people) - JSC in-house concept
- (2) MMU - under development
- (3) ECWS - under study, part of EVA work station concept (may evolve as non-free flyer)

MAJOR INTERFACES: Docking port or temporary attachment mechanism (grapplers, umbilical, hold-down latches); structure/cable avoidance; thruster plume impingement or surface contamination; GEO environment (radiation) constraints

SRT REQUIRED: Concepts being developed in conjunction with, and independent of, SPS studies; SRT covered under related contracts (NAS9-

SPS IMPACTS: Traffic control; crew schedules

OCSE Title: Personnel Orbital Transfer Vehicle (POTV) Category B No. 1.5



Common stage LO₂/LH₂

Life: 30 missions

Payload: 75 passengers + 20 tons (up)

75 passengers (down)

(2nd stage GEO refuel)

~\$12 M/yr

Length: 33.28 m

Diameter: 4.42 m

Total weight: 123 tons

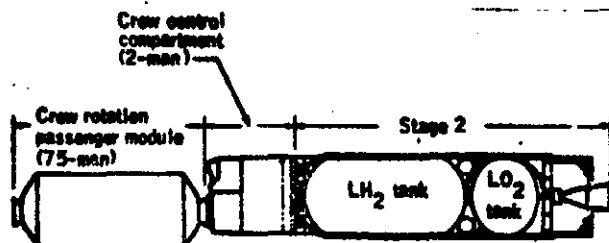
Propellant weight: 106 tons

Number of engines at 66 729 newtons each:

Stage 1: 4 engines

Stage 2: 2 engines

Personnel orbital transfer vehicle (POTV)



Note: POTV, stage 2 refueled at GEO for return to LEO
(propellant weight = 53 metric tons)

Crew rotation POTV configuration
for return from GEO to LEO

Data Source:

JSC 11568, *Initial Technical, Environmental, and Economic Evaluation of Space Solar Power Concepts*, 08-31-76

Operational Description:

A crew rotation passenger module is required for the Earth to LEO and LEO to GEO transfer. The passenger module proposed first flies in the Shuttle payload bay and then is deployed and docked to the POTV at the LEO operations base.

Mass Properties:

Length: 33.28m (109 ft)

Diameter: 4.42m (14.4 ft)

Weight: 123 tons (total)

Propellant: 106 tons

Characteristics:

Functional - Payload: 75 passengers plus 20 tons (LEO to GEO); 75 passengers (GEO to LEO, when refueled in GEO)

Life: 30 missions

Environments: LEO to GEO

Propellants: LO₂/LH₂

Servicing: Prop., electrical, gas, etc (in GEO and LEO)

Physical - Interfaces (Docking): International

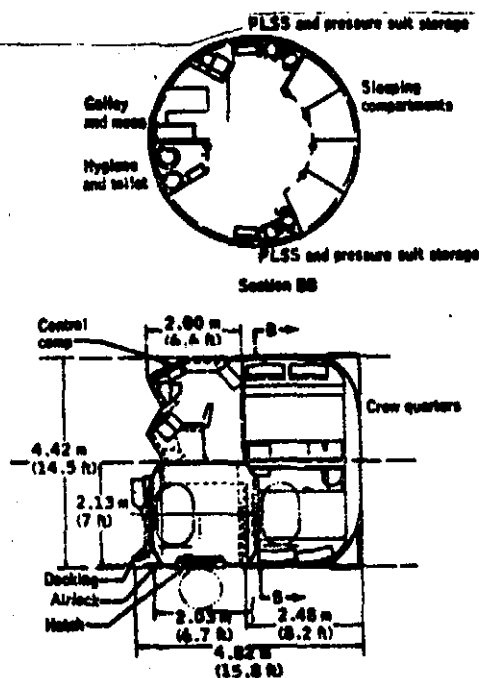
- HLLV or Orbiter
- SPS Construction Facilities
- SPS Assemblies

Servicing Interfaces

- Propellant - require on-orbit fueling and refueling
- Electrical
- Gas
- Life Support

Comments:

JSC concept proposed for early planning purposes. However, crew size requirements for GEO operations have not been focused sufficiently.

OCSE Title: Crew ModuleCategory BNo. 1.6

Crew module concept.

Data Source:

JSC 11568, *Initial Technical, Environmental, and Economic Evaluation of Space Solar Power Concepts*, 08-31-76

Operational Description:

The crew module concept is envisioned as the first and smallest payload to fly with the POTV. A typical mission may consist of a 2 to 4 man crew performing one week of satellite maintenance operations, visiting four satellites with transfers up to 15° longitude between each satellite visit.

Mass Properties: (Crew Module)

Size: 4.82m (15.8 ft) length;
4.42m (14.5 ft) diameter
Mass: 6856 Kg (15,116 lb) to GEO;
5582 Kg (12,315 lb) Return to LEO

Characteristics:

Functional - Payload: 4 passengers plus TBD tons (LEO to GEO)
Mission: Up to 4 man sortie to GEO from LEO and return to LEO
Functions: Construction, contingency, service/maintenance, and test
Services: (Prop. LSS, power) on orbit, LEO and GEO
Propellants: LH_2/LO_2
LEO to GEO Transit Times: 6 hours or less

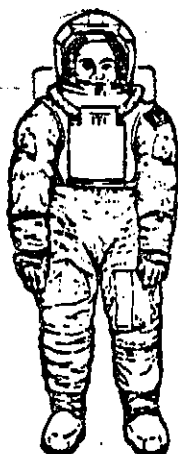
Physical -

Crew: 4 crew for 9-day mission plus 1 day reserves
Crew Quarters: 33.8m (1,194 ft)
Control Compt.: 12.18m (430 ft)
Ancillary Items: Hatches, windows, airlock, docking, arms
Interfaces: Crew module/POTV_L and crew module docking device

Comments:

Proposed concept by JSC is in support of SPS program. For additional data refer to the crew module concept from the Boeing FSTSA Study. The crew module is worked in conjunction with the POTV_L propulsion unit.

OCSE Title: Extravehicular Mobility Unit (EMU) Category B No. 1.7



- Helmet visibility - 120° left and right; 105° down from horizontal;
- EMU Joint Mobility Range/Torque

	Mobility Range (Degrees)	Torque (ft/lb)
a. <u>Shoulder Mobility</u>		
Adduction/Abduction	150°	1.0
Lateral/Medial	200/150°	1.0
Flexion/Extension	180°	1.0
Rotation (X-Z Plane)	90°	0.5
Rotation (Y-Z Plane) (lateral-medial)	120°	0.5
b. <u>Elbow Mobility</u>		
Flexion/Extension	130°	1.0
c. <u>Wrist Mobility</u>		
Flexion/Extension	90°	0.5
Adduction/Abduction	120°	0.5
d. <u>Waist Mobility</u>		
Flexion/Extension	90°	4.0
Rotation	150°	3.0
e. <u>Hip Mobility</u>		
Flexion	70°	2.0
Abduction	10°	2.0

Data Source:

Extravehicular Mobility Unit, JSC RFP
No. 9-BC7-4-6-1P, for Space Shuttle
Program, December 12, 1975

Operational Description:

The NASA design concept emphasis for the EMU is the connection of only four major components by the crewmember in donning the unit. This could reduce operation times and also increase safety aspects by minimizing hoses, straps, and pressure bladder penetrations. The life support subsystems are housed in two modules--one (DCM) integrated onto the front, the other (PLSS/SOP) onto the back of the hard upper torso.

Mass Properties:

Size of PLSS: 61 x 53 x 17.8 cm
(24 x 21 x 7 in.)

Total EMU Weight: 82.6 Kg (182 lb) wet

Characteristics:

Functional - Provide Life Support: In ambient environment from zero to 14.7 psia

Useful Life: 15 years minimum

Operational Time: 7 hours, 6 hours useful EVA time, plus 30 min. ingress/egress and 30 minutes reserve

Emergency O₂: 30 minutes

Cooling Capacity: Sized to handle 1000 BTU/hr metabolic load or 7000 BTU/sortie

Physical - Major Components: gloves, helmet, upper torso and lower torso

Crew: Accommodate crew members within the 5th percentile USAF woman officers to the 95th percentile male flying officers

Service: Gas, liquid, electrical recharge, recycle requires one man within one hour.

Interfaces: Communication RF link and hardwire umbilical, MMU, PRS

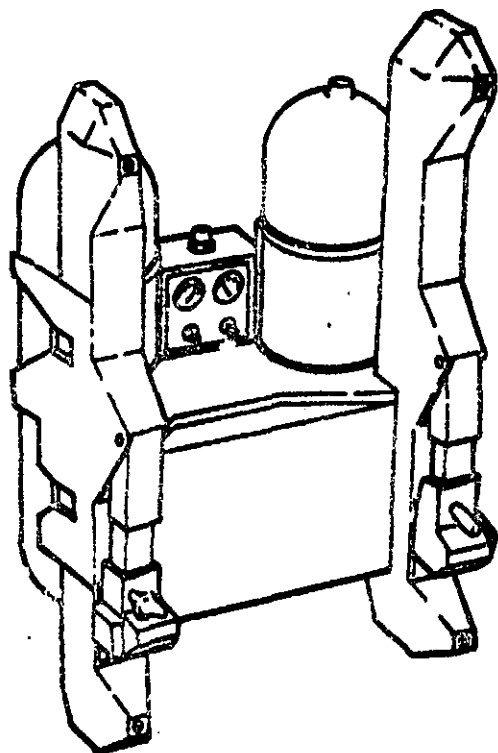
Mounting: Minimum effort for rapid donning/doffing of unit

Comments:

This is a proposed extravehicular mobility unit concept by JSC for the Space Shuttle program. Additional effort in this area would most likely be done by Hamilton Standard Division of United Technologies, Inc. Proposed operational status is 1980.

OCSE Title: Manned Maneuvering Unit (MMU)

Category B No. 1.8



Data Source:

Manned Maneuvering Unit, MCR-75-398,
Revision C, Contract NAS9-14593, System
Design Specification, January, 1977

Operational Description:

The function of the MMU is to provide an EVA crewman with the capability to maneuver in the immediate vicinity of an orbiting spacecraft with six DOF control authority. The MMU attaches rigidly to the PLSS on the crewman's back such that the man, EMU, and MMU form an integral man/machine system for EVA operations.

Mass Properties:

Mass: 102 Kg (225 lbs) wet
FSS = 23.7 Kg (50 lbs)
Dimensions: 135x91x107 cm (53x36x42 in.)

Requirements:

Functional -

Operating Range: Up to 100 m (330 ft) from Orbiter
Sortie Time: 6-1/2 hour EVA without battery recharge or replace
Typical Task: Inspection, photography, retrieval, servicing, etc.

Physical -

Crew: Accommodate personnel within the anthropometric range of 5th percentile USAF women officers to the 95th percentile male flying officers
Service: Recharge cold gas propellant pressure vessel and battery
Interfaces: FSS attachments for stowage, transport, don/doff, servicing, etc.
Mounting: Don/doff MMU by one EVA crewman

Comments:

This proposed unit is complete through the design and test requirements phase.

OCSE REQUIREMENTS DEFINITION SHEET

OCSE INVENTORY NO. 2.0

OCSE CLASS: Structure Attached Transporters

OCSE SUBCLASS: Personnel and Material Transporters

TASK DESCRIPTION: Functional combination of separate personnel transporters and material transporters. See individual requirements sheets. Transport material (up to 700,000 kg) or personnel (1 to 40) over existing structure at or between construction sites. Maximum required range 29 km. Use electrical power if possible; must be able to negotiate joints.

APPLICATIONS TO SPS CONSTRUCTION:

Most transporters can be designed to carry material and/or people. Supply train with a single operator, or work crew transporter carrying required tools, are examples.

No specific identified requirements for dual capability transporter, although most concepts incorporate both.

EXISTING/POTENTIAL CONCEPTS:

- (1) Rail system
- (2) Intrabeam transporter
- (3) Crawler
- (4) Travelling truss

MAJOR INTERFACES: Structure attachment, rail interface; battery recharge station; servicing required.

SRT REQUIRED: Power pickup; rail/beam/transporter designs - structural integrity.

SPS IMPACTS: May impact beam or joint design.

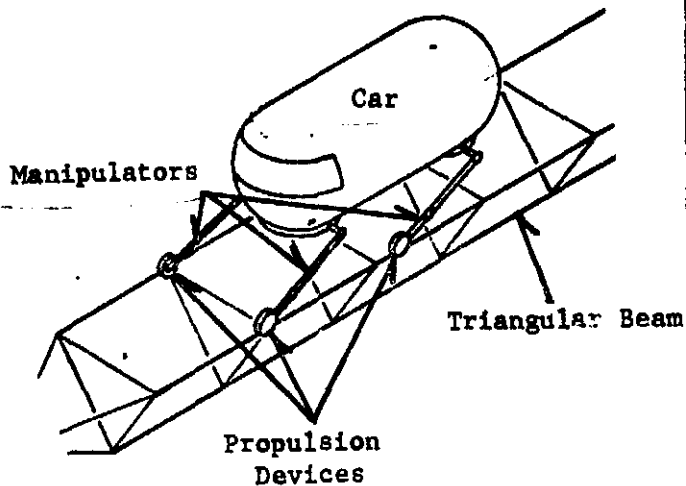
OCSE Title: Beam Traveler Category D No. 2.1

Data Source:

New

Operational Description:

This beam traveler pulls itself along a structural beam with its four manipulators (which have propulsion devices [e.g., wheels] as their end effectors). The following four plates show this vehicle changing beams.



Mass Properties:

Requirements:

Crew: Minimum 2

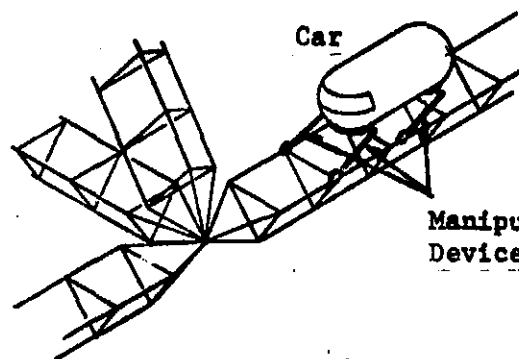
Environment: Any structural members in space

Service: Scheduled

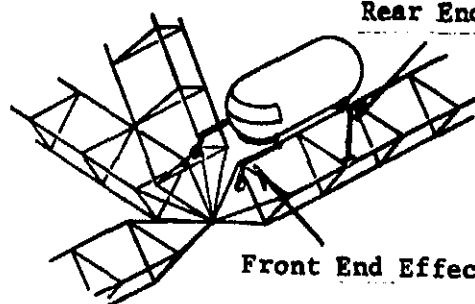
Launch Vehicle:

Comments:

This vehicle has advantages which include: it has no impact on construction; no special size of beam is required; manipulators can double as work tools with multiple end effectors.

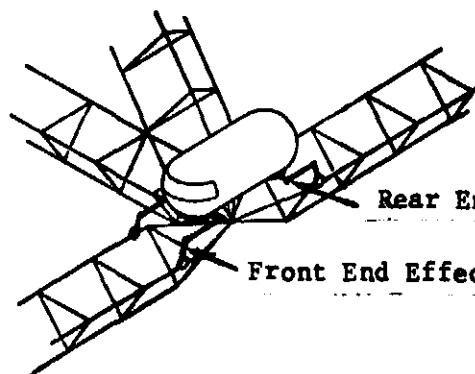


Manipulators with Propulsion
Devices as End Effectors



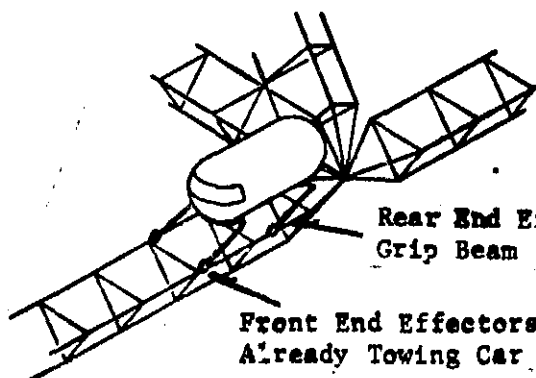
Rear End Effectors Continue Propelling

Front End Effectors Released



Rear End Effectors Released

Front End Effectors Grip Around Joint

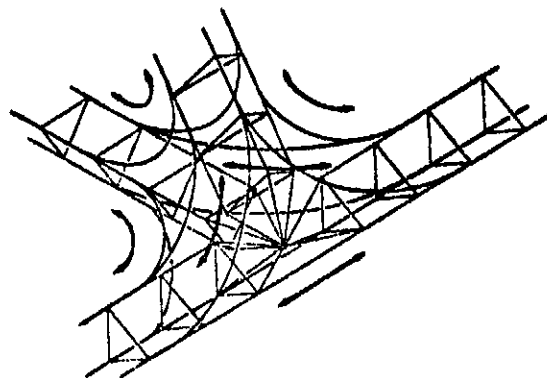


Rear End Effectors
Grip Beam

Front End Effectors
Already Towing Car

OCSE Title: JOINT BY-PASS SYSTEM

Category D No. 2.2



Data Source:

New

Operational Description:

The joint by-pass system (shown in drawing) would be used by those structure-attached transporters which traverse the beam. The by-pass system would most likely be a rigid structure although cable could conceivably be used. The joint by-pass system provides a smooth transition from one beam to the next.

Mass Properties:

Requirements:

Crew: NA

Environment: Structure Attached

Service: Scheduled maintenance/repair

Launch Vehicle:

Comments:

Arrows in the above picture show the direction of the by-pass for each of the three sides of the four beams.

OCSE Title: Static Rail Changer Category D No. 2.3

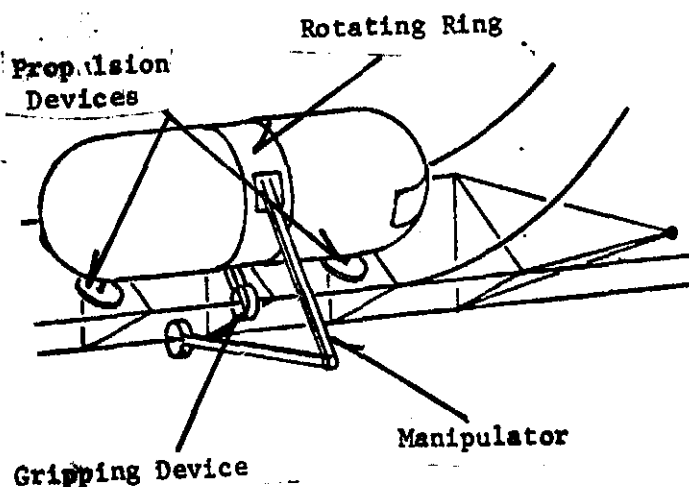
Data Source:

New

Operational Description:

Before approaching a joint having bypasses, this vehicle stops to change sides (if necessary). The entire sequence of changing sides is shown in the four plates that immediately follow this page. The drawing to the left shows the basic parts of such a vehicle.

Mass Properties:



Requirements: Crew: Minimum 2

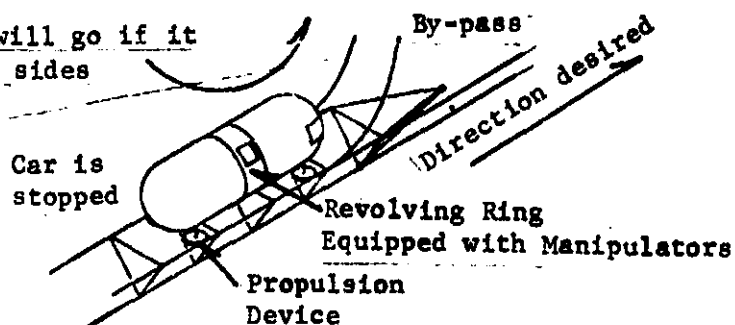
Environment: Triangular beam in space

Service: Scheduled

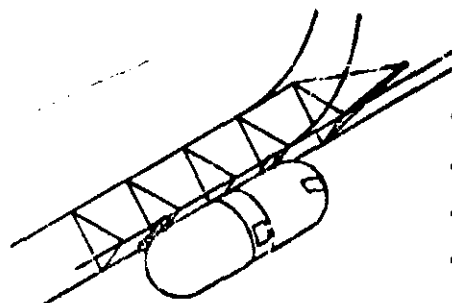
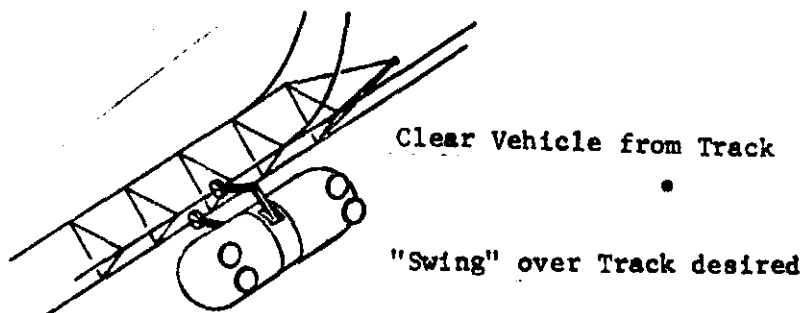
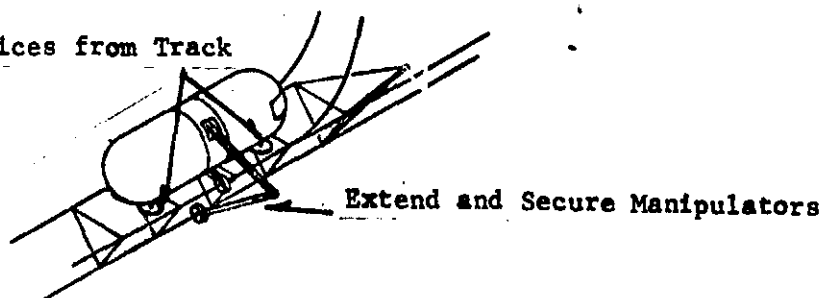
Launch Vehicle:

Comments: This vehicle requires a period of time in which the vehicle is not moving so that it may change sides.

Direction car will go if it doesn't switch sides



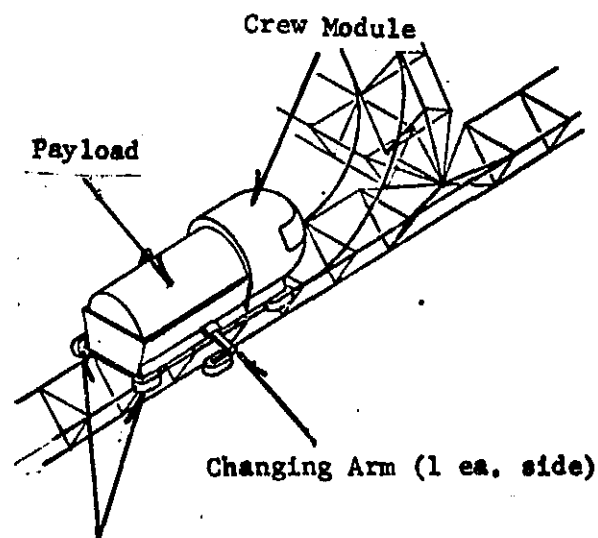
Disengage Propulsion Devices from Track



- Rotate Vehicle
- Align on Track desired by Pilot
- Engage Propulsion Devices
- Retract Manipulators
- Motion continues

OCSE Title: Dynamic Rail Changer

Category D No. 2.4



Data Source:

New

Operational Description:

Shown in the drawing is a modularized version of a cargo carrying rail traveler. This device employs the joint bypass system described elsewhere. Drawings immediately following this page show how this vehicle changes sides (rails) of a beam while moving. Changing arm has rail traveling device on its end.

Mass Properties:

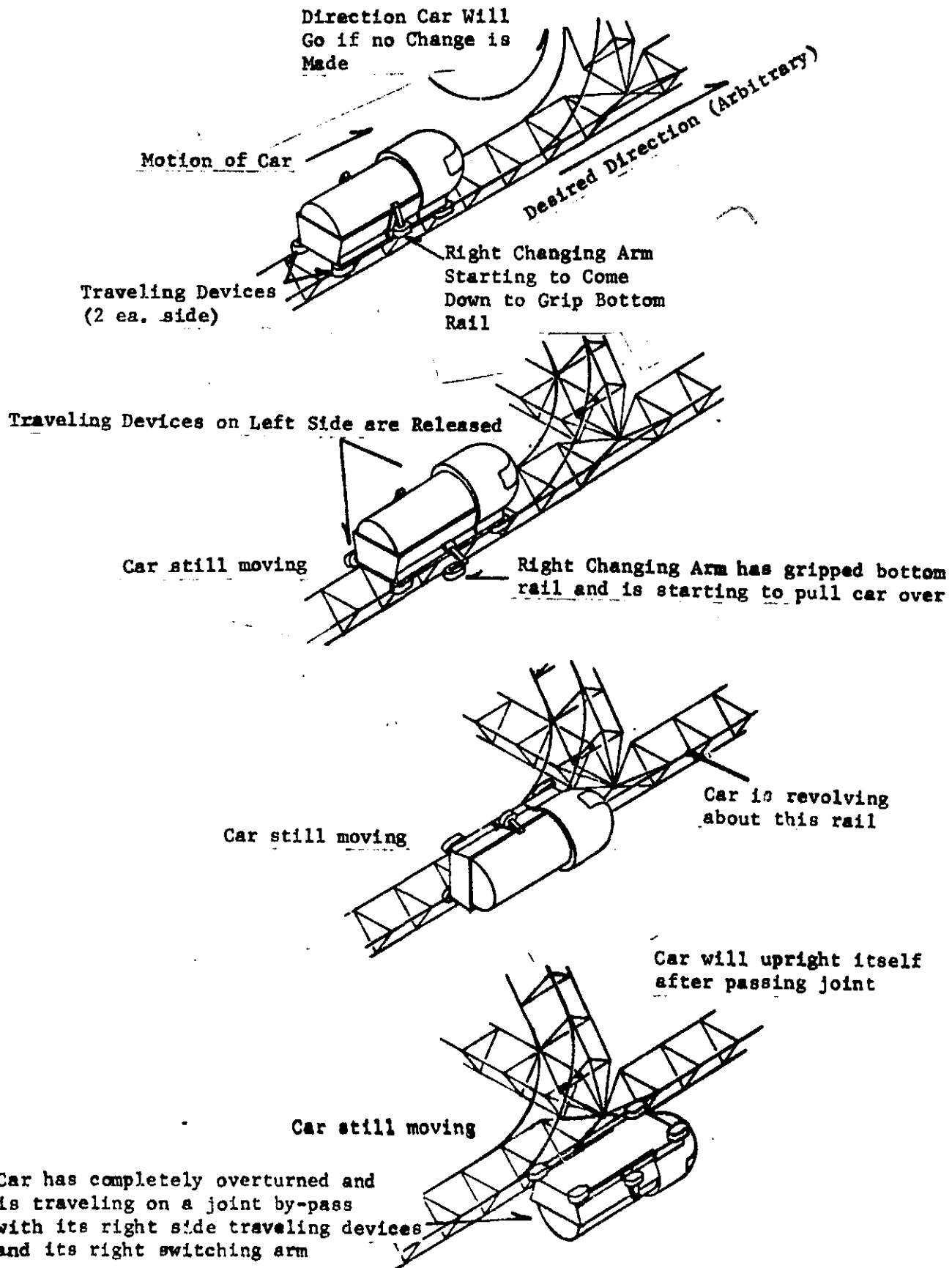
Requirements: Crew: Minimum 2

Environment: Triangular beam in space

Service: Scheduled

Launch Vehicle:

Comments: This vehicle is probably the fastest of the beam traveling devices considered thus far due to its ability to change sides of a beam while moving.



OCSE Title: Combination FF/Rail Vehicle Category D No. 2.6

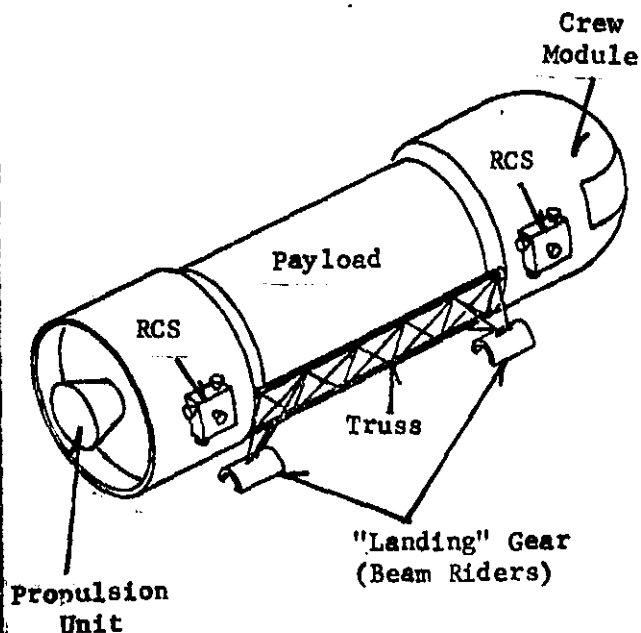
Data Source:

New

Operational Description:

This vehicle would mainly be useful for delivering man and materials to the construction facility. It does away with the need for a docking and receiving station for resupply vehicles. The following plate shows a "landing" sequence for this vehicle. The vehicle lines up with the "runway" (a pointed beam) at a distance and glides in with no power.

Mass Properties:



Requirements:

Crew: Minimum 2

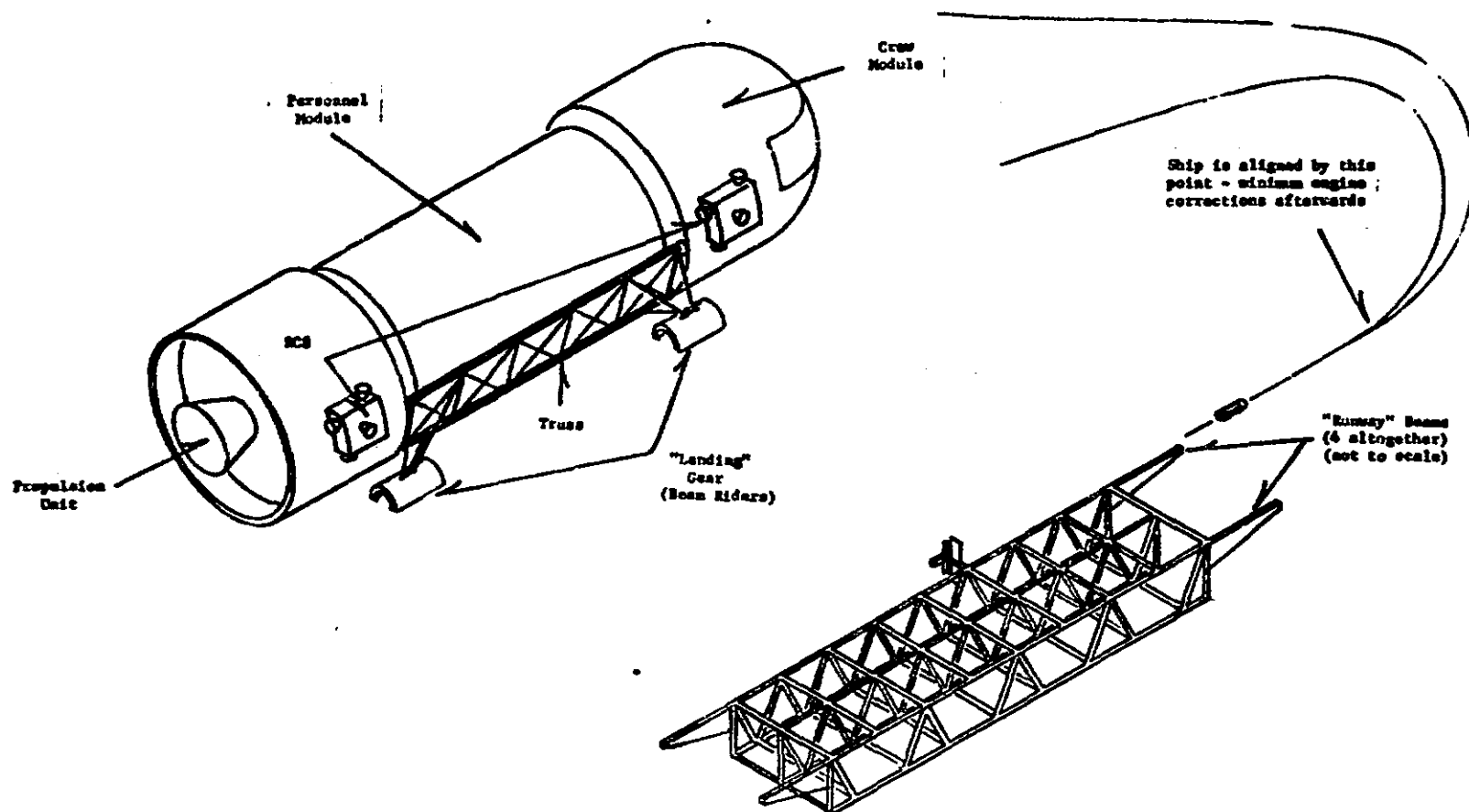
Environment: Space and triangular beams

Service: Scheduled

Launch Vehicle

Comments:

This vehicle would not present any contamination threat to the construction facility because it glides in under no power. It also permits direct delivery to individual machines and locations on the construction facility.



OCSE REQUIREMENTS DEFINITION SHEET

OCSE INVENTORY NO. 2.0

OCSE CLASS: Structure Attached Transporters

OCSE SUBCLASS: Material Transporters

TASK DESCRIPTION: Transport material (up to 700,000 kg) over existing structure (up to 29 km). Use electrical power (either from continuous pickup or rechargeable batteries) if possible. Must be able to negotiate joints.

APPLICATIONS TO SPS CONSTRUCTION:

Boeing Thermal (2.1.2.6) - transport reflector facets (68,000 @ 65 kg each)
5600 meters

Truss type (1.2.2) - transport solar cell blanket mat'l (total 7×10^6 kg)
3900 meters to installers

Column/Cable - (4.1.3.1) - transport concentrator material - 240 rolls,
100 m long, 5000 kg ea; 29 km to installer/facility

MPTS: transport subarrays (8000 @ 200 kg each) - max. distance 500 m (over 1 km
dia. surface)

EXISTING/POTENTIAL CONCEPTS:

- (1) Rail system
- (2) Intra-beam travel
- (3) Traveling truss
- (4) Crawler

MAJOR INTERFACES: Rail interface (beam interface); battery recharge station

SRT REQUIRED: Power pickup; rail/beam/transporter interfaces

SPS IMPACTS: - Impacts, or impacted by, joint design

OCSE REQUIREMENTS DEFINITION SHEET

OCSE INVENTORY NO. 2.0

OCSE CLASS: Structure Attached Transporters

OCSE SUBCLASS: Personnel Transporters

TASK DESCRIPTION: Carry personnel (1 to 40) between locations at construction site, or between work locations. Maximum range - 29 km, pressurized or suited environment. If possible, utilize electrical power available at structure interface or use batteries (recharged at outlet stations) Must be able to negotiate joints, or utilize joint bypasses.

APPLICATIONS TO SPS CONSTRUCTION:

Typically applied to EVA maintenance, distances ~ 500 m to 16 km

No specifically identified requirement to transport large groups of people except during shift changes; personnel transport usually considered in conjunction with other tasks - one or two persons transported.

EXISTING/POTENTIAL CONCEPTS:

- (1) Rail system - on beam surface
- (2) Intra-beam transporter
- (3) Crawler
- (4) Traveling truss

MAJOR INTERFACES: Structure attachment (rail, wheels, etc.); battery recharge station

SRT REQUIRED: Power pickup (if continuous); rail design

SPS IMPACTS: - May impact, or be impacted by, joint and beam design

OCSE REQUIREMENTS DEFINITION SHEET

OCSE INVENTORY NO. 3.0

OCSE CLASS: Handlers

OCSE SUBCLASS: Manipulators (≥ 5 DOF)

TASK DESCRIPTION: Perform tasks requiring multiple degrees of freedom, moderate to high accuracy; masses handled - 5 kg to 700,000 kg; translation distances - 10 m to 900 meters; manipulator lengths required - 10 m to 700 m.

Can be combined with long boom concept, mobile transporter, ECWS, etc.

APPLICATIONS TO SPS CONSTRUCTION:

Boeing Thermal (2.1.1.3) - Handle turbogenerator sets (64 @ 236,000 kg each), 20 x 29 x 5 meters each; translation distance 25 m; hold for mechanical fastening (EVA or more dexterous manipulator)

MPTS - Handle switch gears (16 @ discrete locations, 2000 kg each) for attachment to back of secondary structure - translation distance ~ 70 m (each); structure avoidance during handling.

EXISTING/POTENTIAL CONCEPTS:

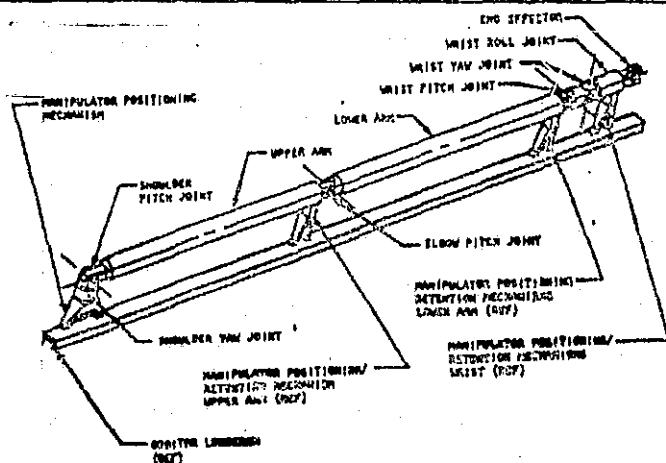
- (1) Fixed base manipulators
- (2) Mobile base manipulators (part of a transport system)
- (3) Dexterous manipulator (short, < 50 m)
- (4) Dual manipulators (tandem operation)

MAJOR INTERFACES: Different end effectors required

SRT REQUIRED: Long manipulator technology

SPS IMPACTS: -Affects SPS construction base/design, activities

OCSE Title: Shuttle Remote Manipulator System (SRMS) Category A No. 3.1



Data Source:

Requirements/Definition Document Remote Manipulator System, JSC-10633, Rev. A, December 15, 1975

Operational Description:

The SRMS is a part of the overall Space Shuttle inflight payload handling system. It is primarily used to deploy payloads from the Orbiter payload bay for release into orbit and to retrieve payloads from orbit and to stow them in the payload bay for servicing or return to earth. The unit assembly is a six DOF system of joints and rigid structural links in an arrangement to give a gimbal order of shoulder yaw, pitch, elbow pitch, and wrist pitch, yaw, and roll.

Manipulator Joint Performance Parameters						
	SHOULDER YAW	SHOULDER PITCH	ELBOW PITCH	WRIST PITCH	WRIST YAW	WRIST ROLL
JOINT RATE, RAD/SEC (MAXIMUM)	.064 (.229)	.004 (.229)	.008 (.327)	.008 (.476)	.008 (.560)	.011 (.638)
TIP SPEED FT/SEC	.20	.20	.139	.049	.052	.03 ORB/SEC
STOP DISTANCE OF TIP FT	2.0	2.0	1.528	.444	.364	0.47 ORB
STOP DISTANCE OF PAYLOAD EXTREMITY, FT	2.064	2.064	2.064	2.064	2.064	2.064
ACCELERATION TIME TO FULL SPEED, SEC	10.00	10.00	10.70	10.61	10.63	10.71

Mass Properties:

Basic Arm: <408 Kg (900 lb)
Total System: 505 Kg (1,113 lb)
Dimensions: See Schematic

Requirements:

Functional - Operating Life: Minimum of 10 years or 500 cycles

Operating Modes: Automatic, manual augmented, and manual direct drive

Handle Payloads: Maximum envelope up to 15 ft dia. x 60 ft long and 65,000 lb

Aid Crewman: Removal and transfer of a crewman in a pressure garment, or personnel enclosure

End Effector Speed: Unloaded shall not exceed 2.0 ft/sec; loaded shall not exceed 0.2 ft/sec and stop within 2 feet

Physical -

Crew: One crewman per SRMS from the Orbiter MSS using two 3-DOF hand controllers

End Effector: Remote interchange of end effectors

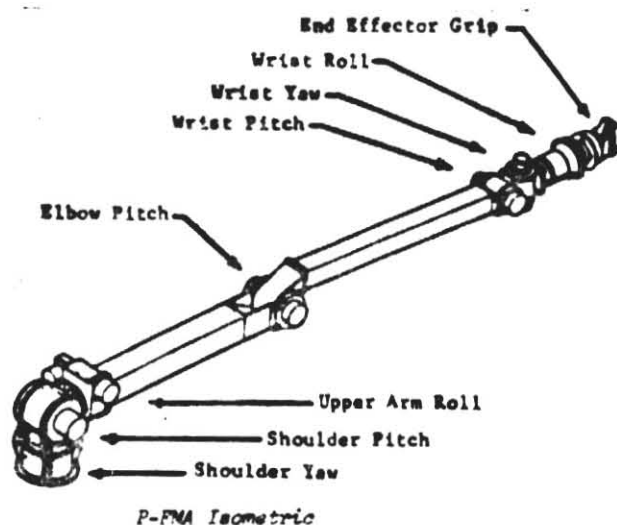
Environment: Zero-g, space

Interfaces: Orbiter mounting, stowage, mechanical, electrical, etc

Power Budget: 660 watts for accuation, 650 watts for thermal heating

Comments:

This unit is out of JSC under contract to SPAR of Canada. It is through PDR (October 1976) and scheduled for CDR on 11-30-77 and on-dock KSC ~ 07-23-79. Schedule indicated first flight on second OFT and operational for third OFT.



P-FMA Drive Characteristics

	UPPER ARM PITCH AND ROLL	UPPER ARM ROLL	ELBOW PITCH	WIST PITCH, ROLL AND YAW
DRIVE MOTOR Type	10	10	10	10
GEARBOX - Vol	17.75	10.37	11.5	6 - pitch and yaw 7 - roll
GEAR REDUCTION	100:1	66:1	100:1	66:1
UPPER ARM (No Load)	200.00	77.00	200.70	100.10
UPPER ARM (No Load)	1.0	1.1	2.0	1.0
UPPER ARM	1000	1000	1000	1000
UPPER ARM (degrees)	+10° pitch -100° yaw	+10°	+17° -100°	+10° pitch & yaw Continuous Roll

Data Source:

Proto-Flight Manipulator Arm (P-FMA),
Contract NAS8-31487, April 1977

Operational Description:

The P-FMA is presently envisioned as a general purpose operational space tool mounted onto an Earth Orbital Teleoperator Spacecraft (EOTS) or like vehicle. Its performance capability provides the flexibility necessary to grip, release, align, manipulate, etc during the basic removal and replacement of modules.

Mass Properties:

Mass: 45.4 Kg (100 lb) [Stowed]
Dimensions: 44x0.9x1.37m (1.4x3x4.5 ft)
0.15x0.15x2.9m (0.5x0.5x9.5 ft)
[Operating]

Requirements:

Functional -

Control: Remotely from Shuttle, Sortie Lab, and/or ground

Reach: 100 cm (4 ft) and 200 cm (8 ft)

Working Envelope: 25 cm (1 ft) minimum to 200 cm (8 ft) from shoulder pitch to wrist pitch axis in a hemispherical shape over mounting interface.

Power: Requires 28 +4V DC at a consumption not to exceed 500 watts

Physical -

Crew: Minimum one crew, IVA at PSS Control and Display Station

Environment: Space

Service: Interchangeable unit mounting and end effector

Interfaces: Mounting, electrical, communications

Comments:

The category identified was B (proposed), however the unit built was a replica of the flight model for the STS.

OCSE REQUIREMENTS DEFINITION SHEET

OCSE INVENTORY NO. 3.0

OCSE CLASS: Handlers

OCSE SUBCLASS: General purpose (≤ 4 DOF) mechanisms

TASK DESCRIPTION: Perform material handling both at short range (< 50 m) and long range (up to 650 meters) from a fixed base. Masses handled range from 10 kg to 700,000 kg; tasks are relatively simple (load/unload), repetitious and require only moderate accuracy. Work surface, from single point, up to 1 km². Actual handling (translation) distances are from 10 meters to 900 meters.

APPLICATIONS TO SPS CONSTRUCTION: (TYPICAL):

MPTS - Subarray handling (load/unload) between transporter (supply vehicle) and installer (subarrays 200 kg ea, 8000 total, 10m x 10m x 0.25m ea.)

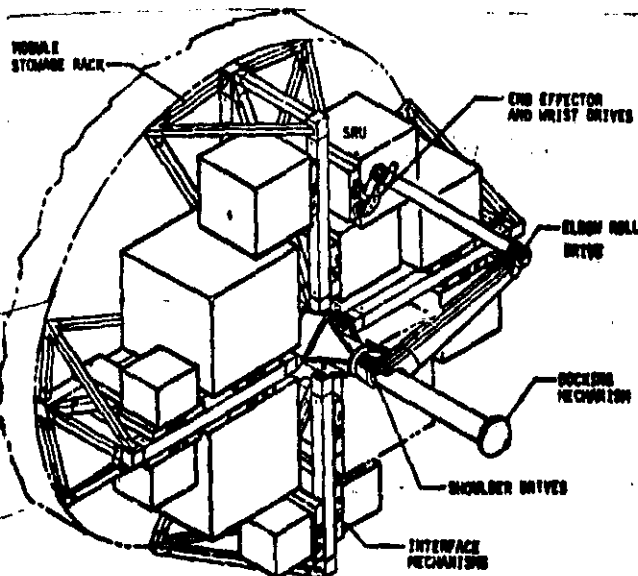
EXISTING/POTENTIAL CONCEPTS:

- (1) Surface Sampler Boom
- (2) On-orbit Servicer Mechanism
- (3) Spar Bistem

MAJOR INTERFACES: Different end effectors required; structural impact of long boom on existing structure; fixed base to structure.

SRT REQUIRED: Long boom construction/design; rotating core (if required)

SPS IMPACTS: -Affects construction base activities



Data Source:

*Integrated Orbital Servicing Study
Follow-On, Mid-Term Progress Review,
Contract NAS8-30820, SA-5, October 1976*

Operational Description:

The on-orbit servicer mechanism as shown is a relatively simple configuration that has both natural and easy growth options. The mission emphasis is on the geosynchronous maintenance case with the capability for axial and radial module removal for a single tier satellite.

Mass Properties:

Servicer Mechanism: 63 Kg (139 lb)
Stowage Rack (12 Inter. Mech): 79 Kg (175 lb)
Dimension: 4.5m dia., 1.8m long (176 in. dia., 71 in. long)

Characteristics:

Functional - Primary Task: Module Exchange

Life: 5 years or 100 missions
Operating Radius: 2.3 m (7.5 ft)
Tip Force: 89 N (20 lb) in either the radial or axial direction
Module Exchange Time: 10 minutes nominal

Physical - Crew: Unit includes both autonomous and manual control options

Docking Device: Requires rigid attachment to satellite being serviced
Service: Minimal component replacement
End Effector: Dedicated to mate with the module interface mechanism
Module Size and Weight: 1m³ (40 in.³) and 318 Kg (700 lb) maximum
Interfaces: Elect. power, mounting points, communications

Comments:

OCSE REQUIREMENTS DEFINITION SHEET

OCSE INVENTORY NO. 4.0

OCSE CLASS: Aligners

OCSE SUBCLASS: Align for joining

TASK DESCRIPTION: Align beam ends (at joints) for fastening or align construction equipment at work location. Alignment required may be straight-line, right angle, parallel beams, planar or specified-angle. Accuracy generally < 2 cm (typical 100 meter span) for beam ends, ± 2 sec for planar angles; actual re-alignment probably performed by manipulator in conjunction with measurement device.

APPLICATIONS TO SPS CONSTRUCTION:

Column/Cable & Truss type (1.1) - align beam builders prior to fastening to structure (line of sight measurement)

MPTS - align sections of extension structure as they are built (planar measurement, straightness measurement) - performed ~ 20 times

Boeing Thermal (2.1.2.2) - Solar concentrator module/beams - 6 places, 2 sec in two planes

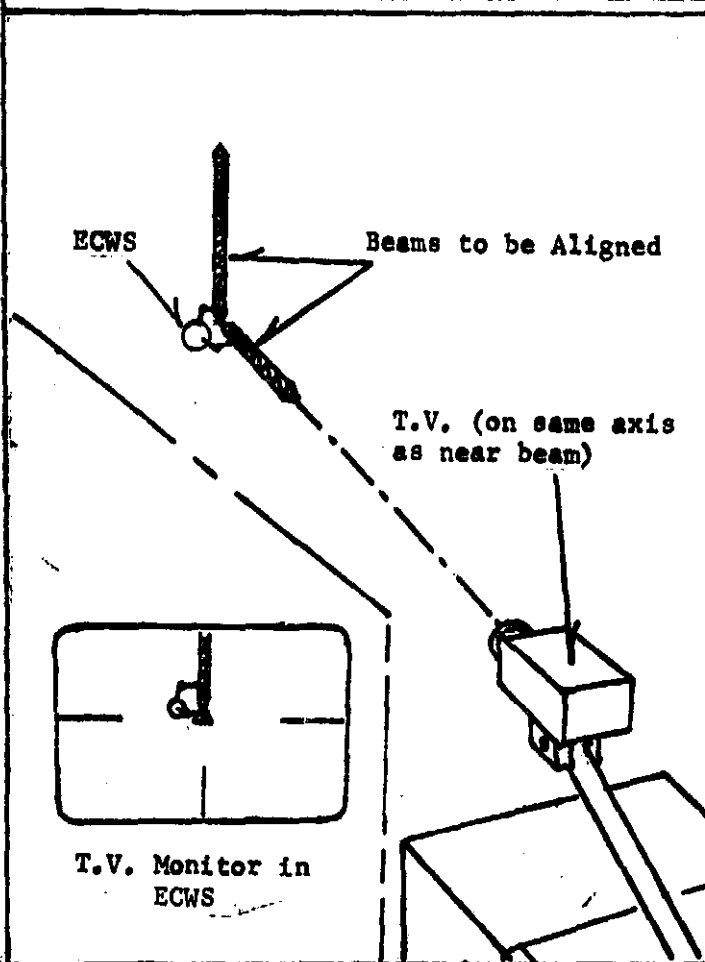
EXISTING/POTENTIAL CONCEPTS:

- (1) Laser
- (2) Video
- (3) Mechanical

MAJOR INTERFACES: Structure, power, lighting

SRT REQUIRED: Accuracy/precision requirements; concept trade-offs; definition of functional requirements (crew-assist by EVA, remote via video, etc.)

SPS IMPACTS: - Critical to structure alignment (collector and transmitter)



Data Source:

New

Operational Description:

T.V. camera unit is maneuvered by RCS so as to view the end of one of two beams to be aligned. Picture is sent to alignment device (e.g., ECWS) to be used as a "gunsight" aligning reference.

Mass Properties:

Requirements:

Crew: Minimum 1, operator in ECWS

Environment: Space, ECWS is free-flyer or structure-attached vehicle

Service: Recharging of RCS gas. Recharging power supply.

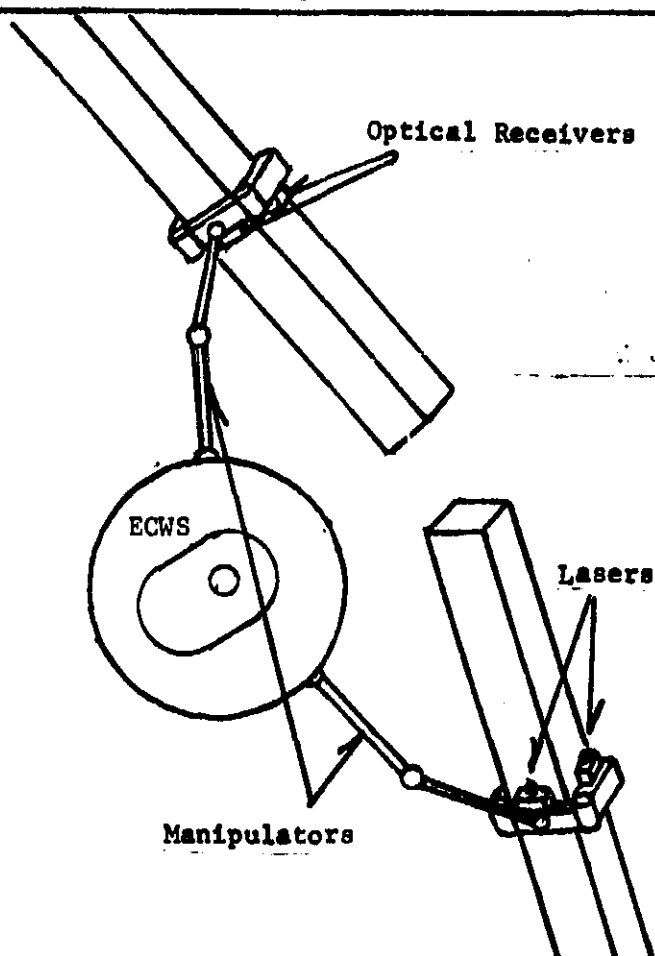
Launch Vehicle:

Comments:

Problems may arise in the initial line-up of the camera on the axis described by one beam and the maintaining of this position. Cannot be used to accurately align long beams because of perspective. The TV camera with antenna could be part of a larger free-flying vehicle (i.e., EOTS) or a mobile structure-attached system.

OCSE Title: LASER ALIGNMENT SYSTEM

Category D No. 4.2



Data Source:

New

Operational Description:

Manipulators grab beams and align lasers and optical receivers parallel to each beam. ECWS operator makes a gross alignment with the manipulators. Optical receivers coupled with computer takes over alignment task at a certain accuracy.

Mass Properties:

Requirements:

Crew: Minimum 1, ECWS operator

Environment: Space, ECWS is free-flyer or structure-attached

Service: Scheduled maintenance

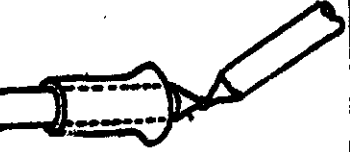
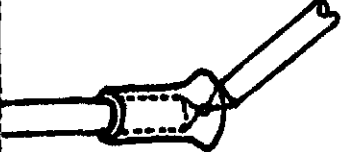
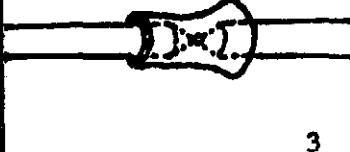
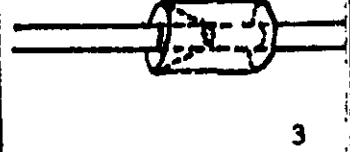
Launch Vehicle:

Comments:

This system has the advantages of quick set-up time and computer help, but is most easily used only for end-to-end alignment. The vehicle on which the manipulators are mounted could be a free flyer or could be part of a mobile structure-attached system. The end effector design (laser/receiver) must accommodate different size beams. The actual joint design may affect align system performance/applicability.

OCSE Title: SELF-ALIGNING GUIDES

Category D No. 4.3

<u>Sleeve</u>  1	<u>Cones</u>  1	<u>Data Source:</u> New <u>Operational Description:</u> Shape of self-aligning guides makes initial gross alignment relatively simple and gradually forces fine alignment. Self-aligning guides have the advantage of making the alignment task simple and uncomplicated.
 2	 2	
 3	 3	

Mass Properties:

Requirements:

Crew: Remote control or, as a minimum, remote monitoring of tasks.

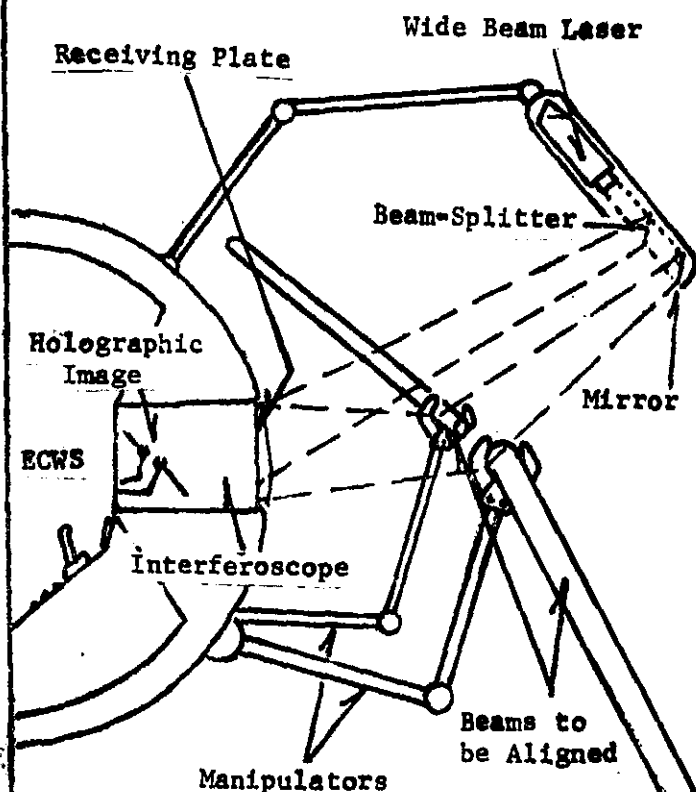
Environment: Space

Service: Set-up of guides

Launch Vehicle: NA

Comments:

Disadvantages of guides include the amount of time required to fit each beam to be joined with the guides. This could be made part of the beam fabrication procedure, providing that the joint design is also made compatible with whatever guide system is used. Odd-angle or multiple-beam joints may make task complex.

Data Source:

New

Operational Description:

Half of the wide beam laser light is reflected by the beam-splitter to the receiving plate of the interferoscope. Other half is reflected by mirror onto work area and is reflected by work area to the receiving plate. The two beams interfere with each other and interferoscope produces a holographic image of the work area from which both operator and/or computer alignment instruments work.

Mass Properties:Requirements:

Crew: Minimum 1, operator in ECWS (Free flying or structure-attached)

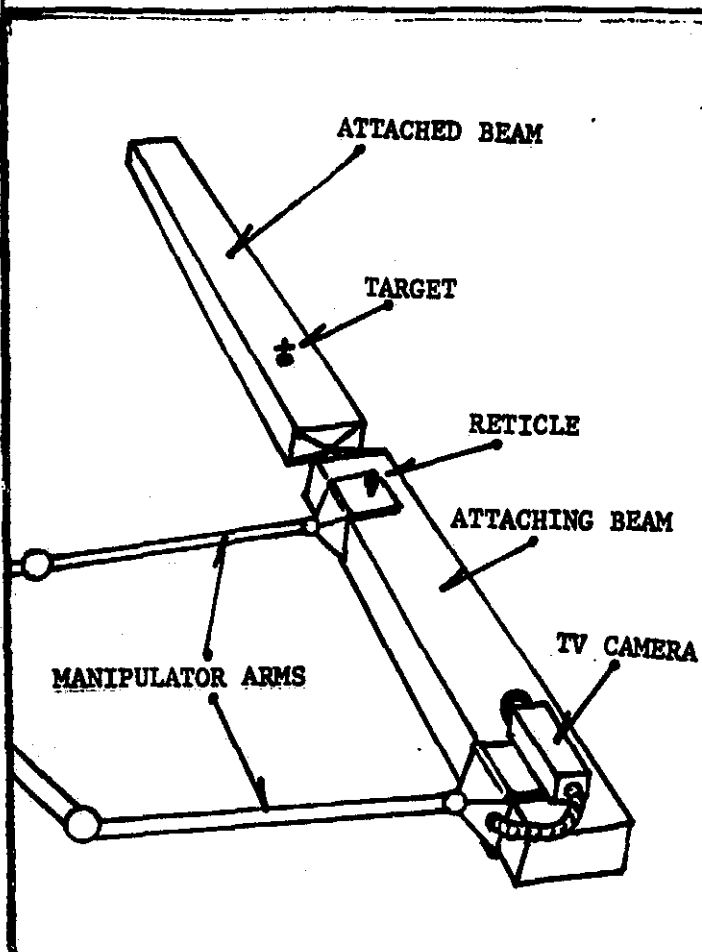
Environments: Placement in ECWS

Service: Service with scheduled maintenance

Launch Vehicle:

Comments:

The interferoscope requires advances in laser holography technology. This system has the advantage of working from a confined reproduction of the work area (alignment sensors are enclosed). A straight "phantom" beam can be superimposed on the holographic image of the actual beams as an alignment guide. Interferoscope is a real time holographic display.

Data Source:

New

Operational Description:

TV camera & reticle & crosshairs located on ECWS manipulator arms and positioned accurately with attaching beam &. Target located accurately on attached beam. Camera image is displayed for ECWS operator who positions both manipulator arms so that crosshairs of reticle align with cross on target and then advances attaching beam until mating takes place, keeping crosshairs lined up.

Mass Properties:Requirements:

Functional -

Crew: Minimum 1, ECWS operator

Environment: Space, ECWS is free-flyer or structure attached

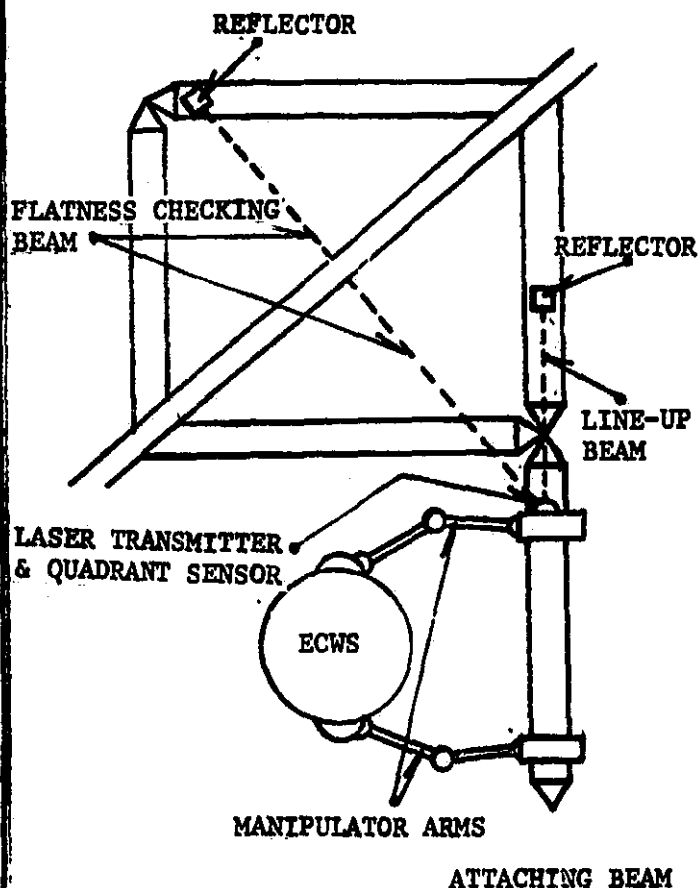
Service: Scheduled maintenance and calibration

Launch Vehicle: N/A

Physical -

Comments:

Requires accurate alignment of camera and reticle to end effectors, and end effectors to attaching beam, also target to attached beam. May want to have target moved from beam to beam, or probably each beam have own target.



Data Source: *Rendezvous and Docking Laser Systems*, MSFC Contracts NAS8-30738 (Norden) and NAS8-20833 (ITT).

Operational Description:

A laser interferometer transmitter and four-quadrant photodiode receiver would be mounted on the ECWS manipulator arm that supports the beam to be attached. To align this beam with the beam to which it will be attached and maintain flatness of the entire structure, a corner reflector (prism) would be mounted on the near beam and the center or starting beam. The transmitter laser scans until lock up on the prism is achieved, and the receiver scans to receive the laser beam returned from the prisms, first to align locally and then check flatness of structure. The receiver signal is sent to the ECWS for beam attitude correction for both alignments and the beam advanced to mate. By using a pulsed coherent laser the range of information can also be determined if required for the local alignment and mating.

Requirements:

Functional -

Crew: Minimum 1, ECWS operator

Environment: Space, ECWS is free-flyer or structure attached

Service: Scheduled maintenance and calibration

Launch Vehicle: N/A

Physical -

Comments:

The corner reflectors must be accurately mounted and the one on the local beam would probably be moved from beam to beam. The end effector containing the laser must have an accurate attachment to the beam being aligned.

OCSE REQUIREMENTS DEFINITION SHEET

OCSE INVENTORY NO. 4.0

OCSE CLASS: Aligners

OCSE SUBCLASS: Surface Flatness Aligners

TASK DESCRIPTION: Measure relative flatness of large surface areas (1 km dia. MPTS) and perform re-alignment as required; accuracy/resolution required, although TBD, will be relatively high. Actual re-alignment may be by EVA - must be performed in concert with measurement device.

APPLICATIONS TO SPS CONSTRUCTION:

MPTS (X.2.4.2) - subarray alignment (continuous surface).

MPTS (X.2.3.1) - main structure alignment (top of structure frames must all be in same plane; discontinuous surface) - SEE ALSO "ADJUST" OCSE class.

EXISTING/POTENTIAL CONCEPTS:

- (1) Video system
- (2) Laser device
- (3) Transit

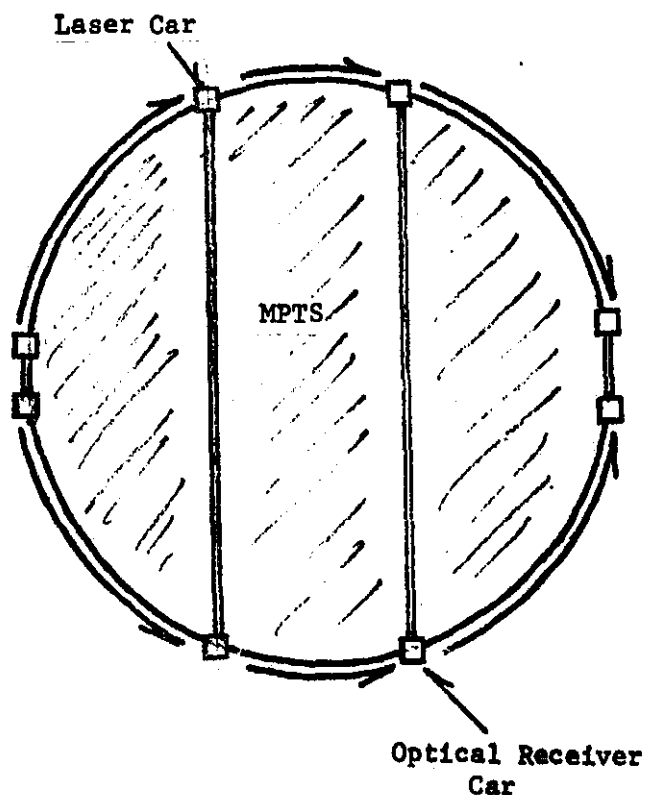
MAJOR INTERFACES: Power, lighting, structure

SRT REQUIRED: Accuracy requirements; concept trade-offs; functional optimization

SPS IMPACTS: - Critical to MPTS transmission efficiency

OCSE Title: LASER FLAT SYSTEM

Category D No. 4.6



Data Source:

New

Operational Description:

Laser car and Optical Receiver car traverse opposite sides of surface to be checked for flatness (e.g. MPTS), laser always pointing at optical receiver. After a "left to right" translation has been made, the procedure is repeated "top to bottom". Unflat areas block laser light and their position is recorded.

Mass Properties:

Requirements:

Crew: Automatic, remote monitoring

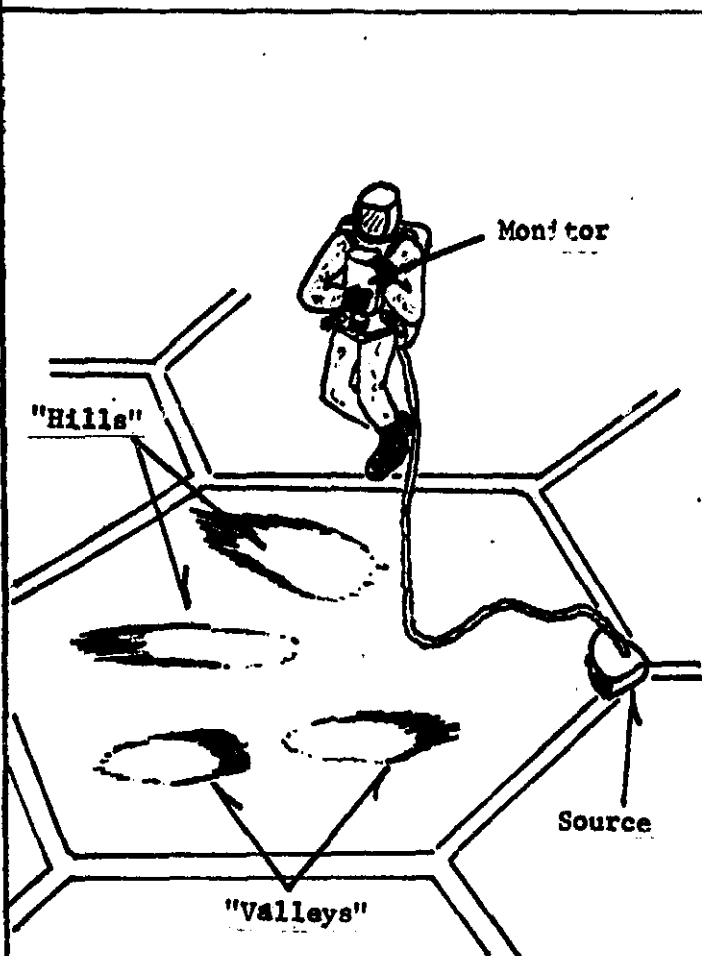
Environment: Structure traveling

Service:

Launch Vehicle: Small, compact system

Comments:

This system cannot "see" "valleys", only "hills". The surface would have to be mapped, and corrections made based on recorded data.



Data Source:

New

Operational Description:

The drawing at the left shows how this technique could be used. A single frequency electromagnetic radiation source (e.g. I.R.) illuminates the surface to be tested. A monitor sensitive to that frequency is used to spot shadowing caused by irregularities of the surface. "Hills" cause crescents, convex away from the source. "Valleys" cause crescents, convex towards the source.

Mass Properties:

Requirements:

Crew: System could be automatic or manual

Environment: Space, EVA hand-held or automated vehicle remotely controlled

Service: Replacement as necessary

Launch Vehicle: Small, compact system

Comments:

This system could be used in an automated vehicle to find irregularities, then used by an astronaut to monitor his corrections. Present technology could detect flatness of approximately one part in 200 down to a variation of 0.1 inches. Technology advances in the next decade should improve this accuracy.

OCSE REQUIREMENTS DEFINITION SHEET

OCSE INVENTORY NO. 4.0

OCSE CLASS: Aligners

OCSE SUBCLASS: Depth and range aligners

TASK DESCRIPTION: Align beams/structure in three dimensions at a joint; actual re-alignment probably accomplished by manipulators controlled via remote station with appropriate display, in conjunction with measurement device.

APPLICATIONS TO SPS CONSTRUCTION:

MPTS extension structure - align beams in up to 4 planes, assure parallelism of beams and perpendicularity of planes as required.

Column/Cable - hub beams (3.1) - assure perpendicularity of six main columns

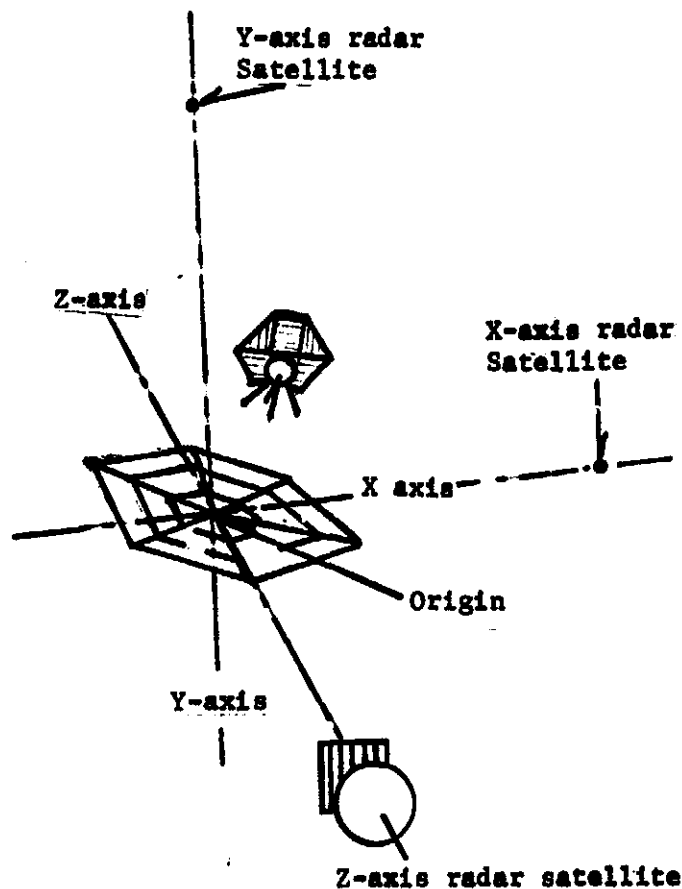
EXISTING/POTENTIAL CONCEPTS:

- (1) Stereo-video
- (2) TV reticle
- (3) Graphic matching (computer assisted)

MAJOR INTERFACES: Structure, power, lighting, display format

SRT REQUIRED: Accuracy/precision requirements; measurement technique; error-signal format

SPS IMPACTS: - Significant to structure alignment, system efficiencies

Data Source:

New

Operational Description:

Three radar transceiving satellites establish a coordinate system through the construction site. Each satellite is able to distinguish and measure individual parts of the construction. These radar images are transmitted to a main receiving station. An ECWS operator would give the receiving station his coordinates and the main receiving station would transmit a computer enhanced 3-view picture of his coordinates (and his work, e.g., beams to be aligned).

Mass Properties:Requirements:

Crew: Computer operated

Environments: Space

Service: Constant checking of placement

Launch Vehicle:

Comments:

This system must await the development of a radar system that has very fine discrimination abilities. This system has the advantage that one main system serves the entire construction facility. Also, every activity in the construction site can be monitored.

OCSE REQUIREMENTS DEFINITION SHEET

OCSE INVENTORY NO. 5.0

OCSE CLASS: Material Fasteners

OCSE SUBCLASS: Manipulator controlled fasteners

TASK DESCRIPTION: Perform mechanical fastening tasks which require moderate external force/torque application of large masses; can be controlled remotely; inter-task manipulator transport may be required; task area access may be limited.

APPLICATIONS TO SPS CONSTRUCTION:

Boeing Thermal - Radiator frames (2.1.1.4) - frame ends butted and welded (24 connections) (beams 120 to 930 kg; up to 950 meters long)
MPTS - Support arm beams (X.2.2.X) - centroidal joint (~ 60 connections)
multiple beams per joint
Truss type - SECS support trusses (3.1) - 2416 centroidal joints
Column/Cable - Power distribution cables (4.1.4) - 4, 17 cm diameter connector plugs

EXISTING/POTENTIAL CONCEPTS:

- (1) Mechanical devices
- (2) Adhesives
- (3) Welding

MAJOR INTERFACES: End effectors (several types); lighting

SRT REQUIRED: Joint design

SPS IMPACTS: - Joint designs (under separate study) affect fastening mechanism design.

OCSE REQUIREMENTS DEFINITION SHEET

OCSE INVENTORY NO. 5.0

OCSE CLASS: Material Fasteners

OCSE SUBCLASS: EVA controlled fasteners

TASK DESCRIPTION: Perform mechanical fastening tasks requiring high degree of dexterity, in areas of limited access, where direct human monitoring is desirable. Tasks may be separated by distances as low as 10m, as high as 75m; therefore, inter-task transport is required. Force/torque fastening loads must be small; individual tasks should require less than 5 minutes.

APPLICATIONS TO SPS CONSTRUCTION:

MPTS - (X.2.6.4) electrical connector fastening at back of subarrays (7000 connections); structure avoidance critical.

Column/Cable - (4.1.3.3) - Prime cable attachment to SECS rings (264 connections); cable avoidance critical

EXISTING/POTENTIAL CONCEPTS:

- (1) Mechanical devices
- (2) Adhesives
- (3) Welding

MAJOR INTERFACES: EVA module interface (cherry picker, MMU, ECWS), lighting; mode of transport between connection tasks, EVA tools

SRT REQUIRED: GEO radiation hazard

SPS IMPACTS: - Affects, is affected by, maintenance/servicing philosophy

OCSE Title: Space Power Tool KitCategory B No. 5.1

Space Power Tool Kit



Space Wrench

Hand Held Bonder

Data Source:

Space Maintenance Tools and Accessories,
Basic Data, MMC, ER 14452, October 1966.

Operational Description:

The space powered tool kit contains a 12V DC rechargeable battery pack which provides 163 watt-hrs at 40 amps. The system was designed and constructed by Martin Marietta for the Gemini program. The tools include: a dead blow hammer, the motor/handle assembly, a power drill, a screwdriver ratchet, worklights, a power impact wrench, a power saw, restraint buttons and applicator, and a small parts holder. MMC has developed one of these tool kits.

Mass Properties:

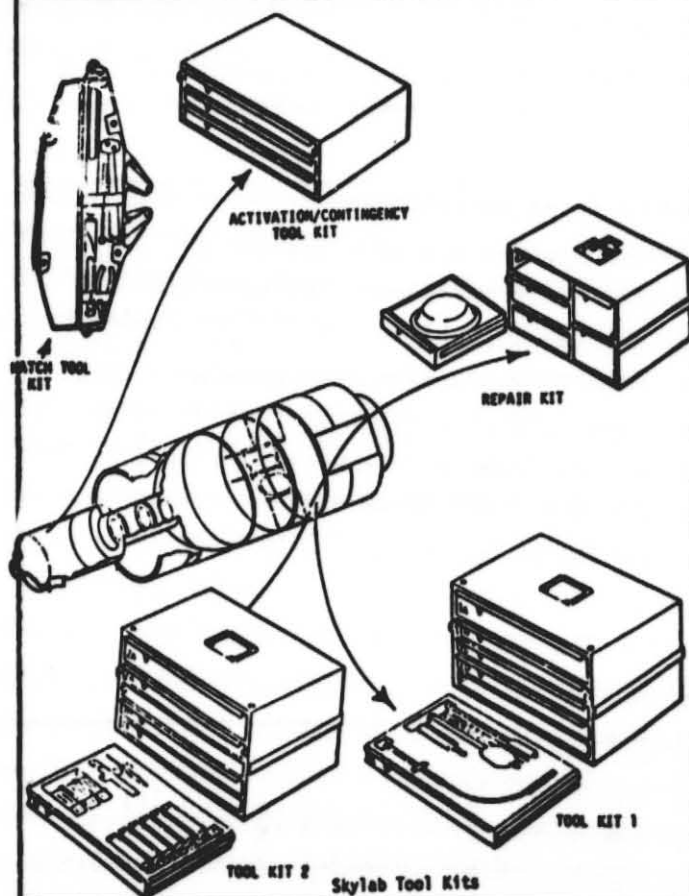
Complete Tool Kit: 17.2 Kg (38 lb)
Size: 37x37x24 cm (14.5x14.5x9.5 in.)

Basic Summary Data:

Item	Wt.	L(in.)	W(in.)	H(in.)	Remarks
Motor	90 oz	7.0	3.0	8.0	12V DC, PM Field
Impactor	42 oz	6.4	2.25	-	85 ft-lb out, 6 in.-oz. reaction
Saw	48 oz	8.0	2.5	4.0	5/8-in. stroke, .030 in. Kerf
Drill	56 oz	8.25	3.25	-	1/4-5/8 holes
Hammer	28 oz	12.5	1.5	4.3	1-1/4 lb dead blow
Screwdriver Handle	12 oz	4.6	1.4	2.7	1/4 in. ratchet drive
Work Light (2)	14 oz	4.0	2.2	-	30° ellipsoidal reflector, 6.9W
Restraint Buttons	1 oz	-	1.13	0.5	8-10 A, 10-12 V, 30 sec for 50 lb
Applicator (2 parts)	12 oz	3.7	1.3	2.8	Indicate 450° Bond Temperature
Battery	5 lb	6.4	2.3	4.9	12V DC Yardney HR-15 Silver Zinc Cells

Comments:

The NASA Space Tool Kit shown here was a study and development effort oriented toward defining in broader terms the scope of the maintenance problems, the human capabilities to perform maintenance and the design characteristics of the tools needed to solve the problems.

**Data Source:**

Skylab Experience Bulletin No. 13, *Tools, Test Equipment, and Consumables Required to Support Inflight Maintenance*, JSC-09547, November 1974

Operational Description:

Tools selected for Skylab were primarily those required for specific tasks that were approved for inflight accomplishments plus a few general purpose tools such as pry bar, hammer and Swiss army knife. Two primary complaints were voiced by Skylab crewmen regarding tools. First, all the necessary tools were not included; and secondly, if a tool was available, it sometimes did not perform well because of safety requirements that had been imposed to render the tools ready for flight. One basic recommendation by the crewmen was to have all tools grouped in one specific area.

Mass Properties: Five Basic Kits:

Tool Kit 1 and 2:
Portable Repair Kit:
MDA Hatch Kit:
Activation/Contingency Kit:

General Characteristics:**Functional -**

Operation: All basic Skylab tools are hand operational
Functions: Both general and dedicated capability requirements
Crew: Single hand operation

Physical -

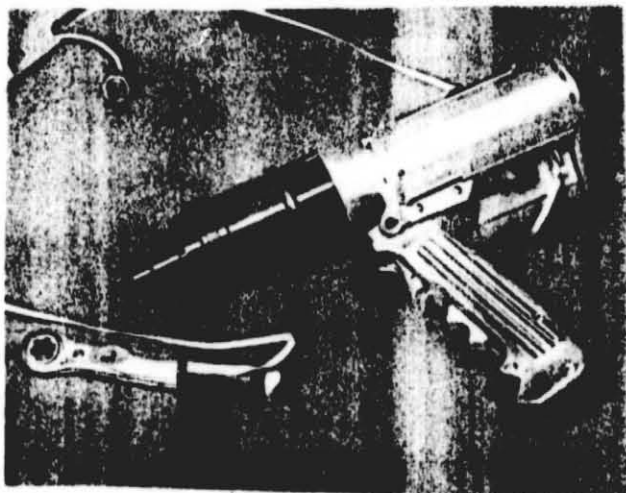
Sizing: Capable of being used with a PGA gloved hand.
Holding Techniques: Elastic strips, see-through pouches.
Handling Interfaces: Tether rings, Velcro straps, Velcro tabs
Stowage: Some tools fit tightly into the drawer cutouts while others were so loose they were not restrained at all.

Comments:

It should be noted that none of the tools in the initial tool inventory were designed for EVA usage. In order to properly interface with the EVA glove, tool handles had to be enlarged to wrapping them with tape. Since many of the tools were not equipped with tethers or tether attach points, it was necessary to also use tape to attach the required tethers. However, the tools proved to be adequate for EVA after handles were taped and tethers attached.

OCSE Title: Space Power Tool

Category A No. 5.3



Data Source:

Space Maintenance Tools and Accessories,
Basic Data, ER 14452, October 1966.

Operational Description:

The space-power tool and restraint assembly were designed and developed specifically for the NASA/USAF Gemini D-16 Experiment. Qualification testing was conducted with the space power tool stowed in the restraint assembly when subjected to launch environment stresses. The performance capability of this unit was not oriented toward any specific program and the tools represented prototype solutions.

Mass Properties:

Power Tool Weight: 3.4 Kg (7.6 lb)
Total Weight: 8.3 Kg (18.5 lb)
Size, Stowage: 71x18x16.8 cm (28x7x6.6")

Requirements:

Functional - Capable of performing general drilling and bolting tasks.
Output Torque: Exceeds 45 foot-pounds developed on 1/2-in. NF AN-type bolt
Operating Voltage: 6 to 7 volts
Work Capacity per Battery Charge: Impacting - 100 3-sec bursts
Drilling Time: 8 to 10 minutes running time

Physical -

Crew: Operate with single hand with space suit glove
Service: Battery recharge
Interfaces: Replaceable 1/2-inch drive chuck

Comments:

The Space Power Tool and Restraint Assembly was flown on both GT-8 and GT-11, however no operational tests were performed during these flights. Three flight sets and four qualification and training sets of equipment were delivered to Aeropulsion Laboratories at Wright Patterson AFB (APFT - Mr. C. B. May).

OCSE Title: Apollo Lunar Surface Drill

Category A

No. 5.4



Data Source:

*Apollo Lunar Surface Drill (ALSD),
MCR-71-35, Contract NAS9-9462,
August 1971*

Operational Description:

The ALSD provided the means to emplace the Heat Flow Experiment probes into the lunar soil and to acquire a deep subsurface core sample. The first requires the drilling of two holes to a depth of 10 ft each. The core sample is acquired by drilling titanium stems into the lunar soil, removing, and capping for transport to Earth.

Mass Properties:

Mass: 13.6 Kg (30.0 lbs)
Dimensions: 17.8x24.4x101.7cm
(7x9.6x22.7 inches)

Requirements:

Functional - Rotary - percussion drilling principle.

Drilling: 1.032-in. dia. hole in dense basalt at 1.5 in./min.

Force: Download of between 22 and 66 N(5 and 15 lbs)

Flexibility: Replaceable bit capability

Physical -

Crew: One crew for hand-held operation

Environment: Space, vacuum, 1/6-g during operation

Service: Electrical recharge

Mounting: Mechanical interfaces for launch and descent vehicles

Comments:

During Skylab program this unit was modified to operate as a material cutter. For SPS applications, similar modifications would be employed to make use of the drive unit concepts. See Sheet 2 of 2.



OCSE REQUIREMENTS DEFINITION SHEET

OCSE INVENTORY NO. 5.0

OCSE CLASS: Material Fasteners

OCSE SUBCLASS: Fasteners inherent in structure

TASK DESCRIPTION: Provide fastening mechanism (as part of basic structure) which accepts mating material and completes fastening task automatically; used for elements which must (or may) be periodically removed/replaced. .

APPLICATIONS TO SPS CONSTRUCTION:

Column/Cable (3.0) - Main/prime cable reel assemblies (104 reels) - reel base plate mechanically attached to facility structure

Boeing Thermal (2.1.1.3) - turbogenerator sets (64) - mechanically fastened to shell panels (helium line joints accomplished separately)

MPTS (X.2.6.1) - switch gears (16) attached to substructure via latches

EXISTING/POTENTIAL CONCEPTS:

- (1) Mechanical joint
- (2) Impact (contact) latches

MAJOR INTERFACES: Handler to bring materials into contact

SRT REQUIRED: Joint design (Cast-lock/Butt-centroidal)

SPS IMPACTS: Joint/latch design impacted by construction/maintenance philosophy

OCSE REQUIREMENTS DEFINITION SHEET

OCSE INVENTORY NO: 6.0

OCSE CLASS: Adjustment Devices

OCSE SUBCLASS: Beam positioners

TASK DESCRIPTION: Adjust beam positions to achieve proper configuration (see HANDLERS)

APPLICATIONS TO SPS CONSTRUCTION:

Column/Cable Facilities (3.3) - adjust beams to make 6 facilities mutually perpendicular (18 adjustments)

Boeing Thermal (4.1.3) - adjust spinal truss length to make axes of SCs parallel - required over 3 spans of 4000 meters

EXISTING/POTENTIAL CONCEPTS:

- | | | |
|------------------|---|--------------|
| (1) Manipulators | } | see HANDLERS |
| (2) EVA/Tools | | |
| (3) EOTS | | |

MAJOR INTERFACES:

SRT REQUIRED: Alignment/adjustment over long spans (4 km)

SPS IMPACTS: -

OCSE REQUIREMENTS DEFINITION SHEET

OCSE INVENTORY NO. 6.0

OCSE CLASS: Adjustment Devices

OCSE SUBCLASS: Inherent with structure adjusters

TASK DESCRIPTION: Provide adjustment capability by incorporating device into the element itself (e.g., screw jack in beam builder mount); device activation can be remote or direct (EVA task may be required) - measurement technique must be incorporated.

APPLICATIONS TO SPS CONSTRUCTION:

Facility tension rods (C/C - 1.1.4, TT - 1.1.4) - adjust 12 to 144 rods in pairs to align longitudinal beams

MPTS subarrays (X.2.4.2) - adjust (7854) subarrays to obtain desired surface flatness (may be accomplished instead by phase adjustments)

EXISTING/POTENTIAL CONCEPTS:

- (1) Screw jack
- (2) Linear motion wedge

MAJOR INTERFACES: Measurement device; lighting

SRT REQUIRED:

SPS IMPACTS: -

OCSE REQUIREMENTS DEFINITION SHEET

OCSE INVENTORY NO. 6.0

OCSE CLASS: Adjustment Devices

OCSE SUBCLASS: Cable tensioners

TASK DESCRIPTION: Provide capability to release/retension cables periodically; measure tension (3000 Newtons max.); for some applications (MPTS) tensioner requires transport between tasks; for others (C/C), tensioner may be part of a reel assembly in a facility.

APPLICATIONS TO SPS CONSTRUCTION:

Column/Cable (4.1.2.5) - Main/prime cables - release/retension every 100 meters (144 times), up to 96 cables involved

MPTS frames (X.2.3.1) - adjust radial cables between concentric rings to bring frame tops into single plane (cable lengths ~175 meters)

Boeing Thermal (2.1.2.4) - SC tension cables - adjust to stiffen structures (24 - 36 times)

EXISTING/POTENTIAL CONCEPTS:

- (1) Turn buckle
- (2) Cable bender (tensioner device)

MAJOR INTERFACES: Cable gripper, routing; cable/structure fastenings

SRT REQUIRED: Cable dispenser, take-up reel design; tension measurement technique

SPS IMPACTS: -

OCSE REQUIREMENTS DEFINITION SHEET

OCSE INVENTORY NO. 7.0

OCSE CLASS: Checkout Devices

OCSE SUBCLASS: Input simulators for checkout

TASK DESCRIPTION: Accomplish operability/performance checks on SPS subsystems by providing an appropriate stimulus to which the subsystem should respond in a particular manner; measure/detect response and evaluate subsystem condition. Access to the subsystem may be restricted. (See MONITORING)

APPLICATIONS TO SPS CONSTRUCTION:

Boeing Thermal (2.1.1.3) - turbogenerator set checkout (64 sets)

MPTS - (X.2.6.1) - switch gear (16) checkout

MPTS - (X.2.8.1) - pointing system computer checkout

MPTS - (X.2.4.2) - subarray phase control checkout

EXISTING/POTENTIAL CONCEPTS:

- (1) Sun source
- (2) Heat source
- (3) Electrical supply
- (4) Force/torque

MAJOR INTERFACES: Handling/fastening of checkout device to or near subsystem; power, lighting

SRT REQUIRED:

SPS IMPACTS: -Need definition of test conditions required; maintenance/servicing philosophy is significant to test requirements definition.

OCSE REQUIREMENTS DEFINITION SHEET

OCSE INVENTORY NO. 7.0

OCSE CLASS: Checkout Devices

OCSE SUBCLASS: Data feedback sensors

TASK DESCRIPTION: Utilization of pre-installed sensors, or of characteristics of subsystem itself (e.g., stress build-up visible under X-ray) to perform checkout based on data feedback

APPLICATIONS TO SPS CONSTRUCTION:

Boeing Thermal (2.1.1.5) - Leak check (He & NaK) in PCS piping (8 systems)

MPTS (X.2.6.3, X.2.5.1, X:2.8.2) - electrical continuity in electronics subsystems (phase control, pointing control, power distribution) ~2000 lines to check

Boeing Thermal/Column-Cable/Truss type - Joint checks, fastener integrity checks (~ several hundred checks)

EXISTING/POTENTIAL CONCEPTS:

- (1) X-ray (welds)
- (2) Ultrasonic
- (3) Electrical continuity
- (4) Range/distance measurement technique

MAJOR INTERFACES: Handling/fastening of checkout device to or near subsystem, power, lighting

SRT REQUIRED:

SPS IMPACTS: Test requirements definition needed; maintenance/servicing philosophy significant to that definition

OCSE REQUIREMENTS DEFINITION SHEET

OCSE INVENTORY NO. 8.0

OCSE CLASS: Monitoring Devices

OCSE SUBCLASS: Remote viewing

TASK DESCRIPTION: Provide capability to view by indirect means various SPS construction activities; monitoring requirement most often occurs in conjunction with other functions (handling, fastening, adjusting, aligning, checkout) and maybe necessary to complete a given task or may merely be supervisory; monitoring may be real time or delayed, of other OCSE or of automatic CE process.

APPLICATIONS TO SPS CONSTRUCTION:

MPTS (X.2.5.1) - electronics packages interconnections (~ 7000)

Boeing Thermal (2.2.8.1) - rotary transformer assembly installation (one time)

General Assembly Surveillance - multiple camera positions

C&D stations

EXISTING/POTENTIAL CONCEPTS:

- (1) Stereo video
- (2) Photographic
- (3) Computer graphics
- (4) Special wavelength (e.g., IR) monitoring

MAJOR INTERFACES: Lighting, power

SRT REQUIRED:

SPS IMPACTS: Construction base design determines major monitoring stations

OCSE REQUIREMENTS DEFINITION SHEET

OCSE INVENTORY NO. 8.0

OCSE CLASS: Monitoring Devices

OCSE SUBCLASS: Direct Viewing

TASK DESCRIPTION: Provide capability to view by direct means various SPS construction activities; monitoring requirement most often occurs in conjunction with other functions (handling, fastening, adjusting, aligning, checkout); monitoring may be necessary to complete a given task or may merely be supervisory.

APPLICATIONS TO SPS CONSTRUCTION:

Column/Cable, Truss (1.1.4) - facility beam alignment - monitor measurement of 30 to 350 angles

MPTS (4.2.2.1) - monitor ball joint installation

General surveillance of SPS assembly

EXISTING/POTENTIAL CONCEPTS:

- (1) Binocular Camera
- (2) Reticle
- (3) Wide-field Telescope

MAJOR INTERFACES: Need line-of-sight view; lighting; monitoring station locations on structure

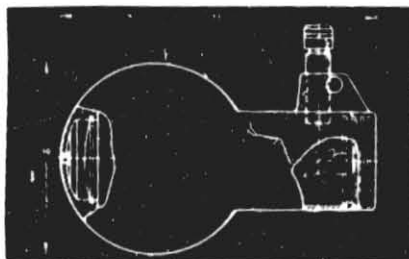
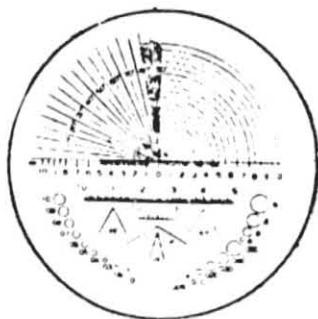
SRT REQUIRED:

SPS IMPACTS: Direct viewing is function of particular task - assume viewer is in vicinity by virtue of transporter/handler

OCSE Title: DIRECT VIEWING MONITOR DEVICES

Category C

No. 8.1



Data Source:

Commercial

Operational Description:

Binocular Camera: This instrument is used for telescopic viewing and subsequent photographing of a distant object. Shown is a commercially available, 7 x 50 unit having a 6°25' F.O.V., 1/60 - 1/125 - 1/250 sec. exp. time, and automatic rewind.

Reticle: Reticles could be used in conjunction with direct viewing devices to measure angles, diameters, distances, etc. Several types of reticles could form a kit to accompany the viewing device.

Wide-Field Telescope: This device might be used as a monitoring device because of its bright, high-clarity view.

Mass Properties:

Requirements:

Functional -

Physical -

Comments:

OCSE REQUIREMENTS DEFINITION SHEET

OCSE INVENTORY NO. 8.0

OCSE CLASS: Monitoring Devices

OCSE SUBCLASS: Instrumentation displays

TASK DESCRIPTION: Provide capability to monitor equipment or task status via remote data received from instruments mounted at task location; monitoring requirement generally occurs in conjunction with other functions (handling, aligning, fastening, adjusting, checkout) and can be necessary to the adequate completion of the task or may be merely supervisory. Display of data may be required in real time, or may be delayed.

APPLICATIONS TO SPS CONSTRUCTION:

EXISTING/POTENTIAL CONCEPTS:

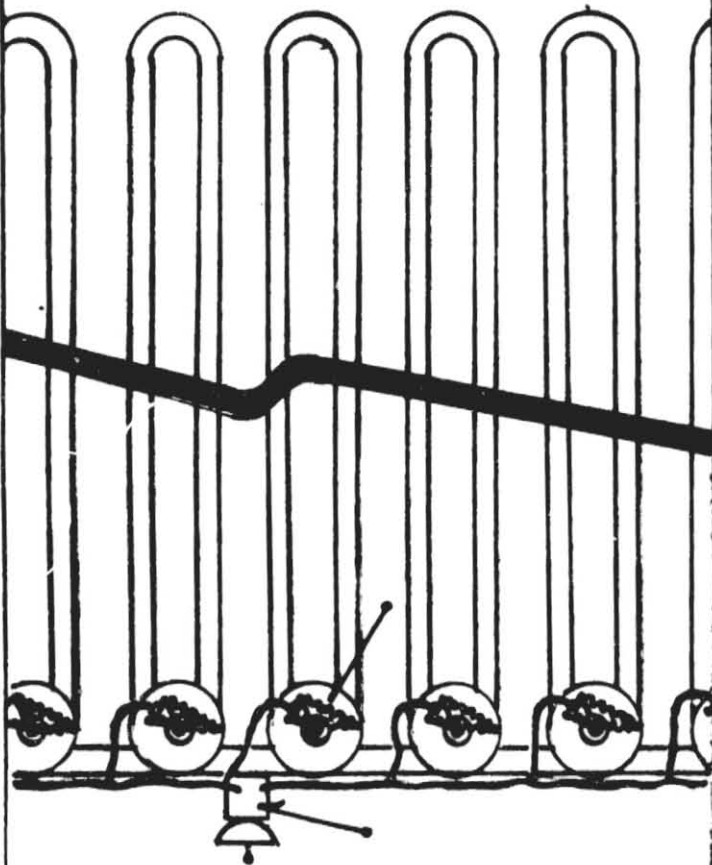
- (1) Strain gages
- (2) Temperature indicators
- (3) Leak detector
- (4) Contamination monitor

MAJOR INTERFACES: Monitoring devices required are direct function of task being performed

SRT REQUIRED:

SPS IMPACTS:

OCSE Title: FLUID LEAK ALARM AND ISOLATION VALVE Category D No. 8.2



Data Source:

New

Operational Description:

See also
Sheet 2 of 2

Normal fluid flow shown by solid arrows. Left valve arm prevents dynamic pressure from entering static pressure chamber when in normal position. Pressure on both sides of right valve arm cancel under normal conditions. Puncture in line reduces pressure on right side of right valve arm. Pressure in static pressure chamber pushes right valve arm into actuation position. Actuation springs move valve arms into final positions, breaking restrainer and closing alarm switch. Fluid now flows in direction of dashed arrow.

See also Sheet 2 of 2.

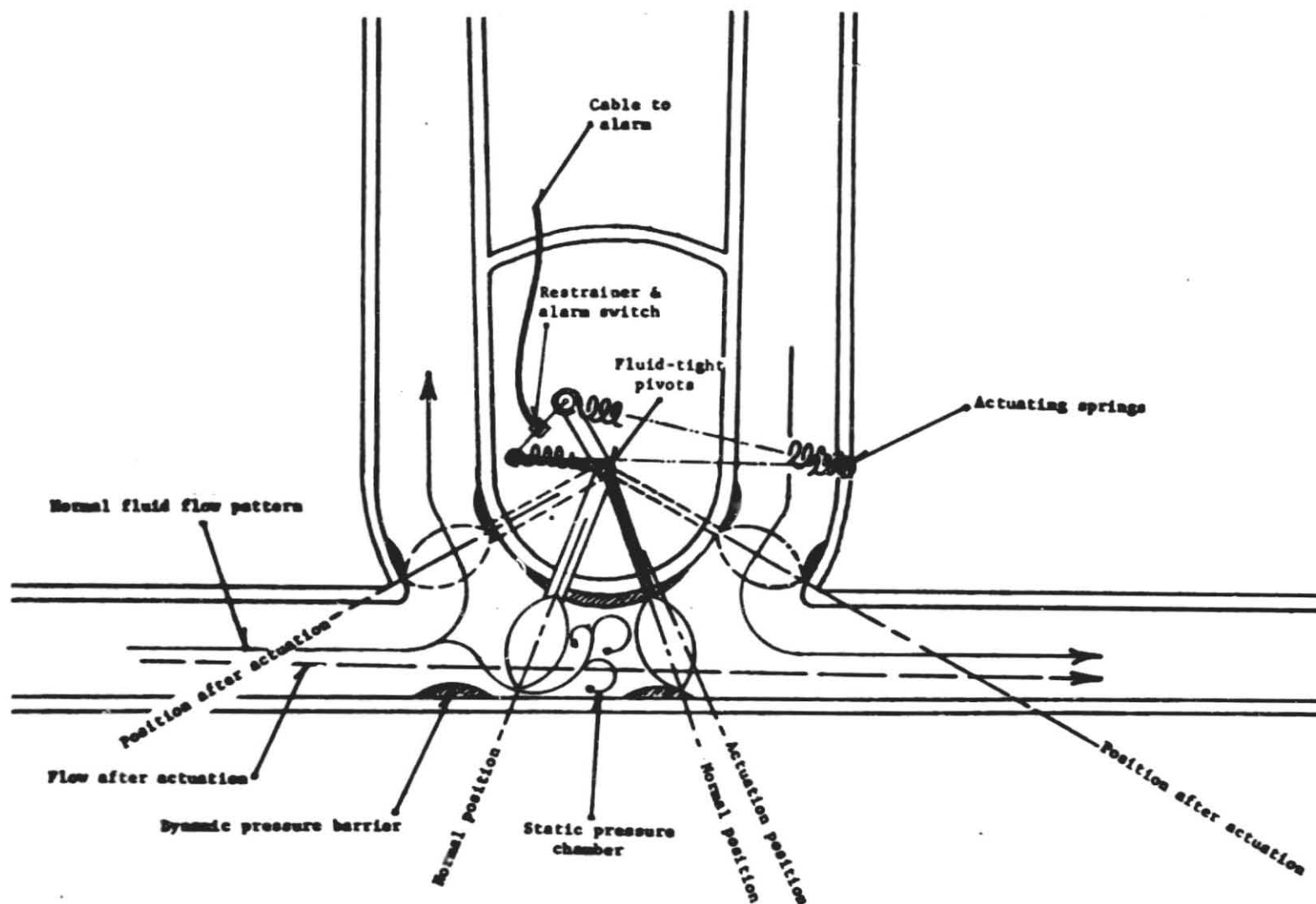
Mass Properties:

Requirements:

Functional -

Physical -

Comments:



FLUID LEAK ALARM AND ISOLATION VALVE

OCSE REQUIREMENTS DEFINITION SHEET

OCSE INVENTORY NO. 9.0

OCSE CLASS: OCSE Support Equipment

OCSE SUBCLASS: Docking Devices

TASK DESCRIPTION: Provides docking interfaces or mechanisms to allow vehicles to attach to structure, modules or other vehicles. The majority of TRANSPORT tasks require or assume a compatible docking device at the end of travel. In some cases, the device required is simply a temporary attachment mechanism to allow crew/material transfer; in other cases, a fully enclosed (pressurized) docking port is required. Additional requirement for docking/attachment of large structures.

APPLICATIONS TO SPS CONSTRUCTION:

Column/Cable (4.1.3.1) - Concentrator material transporter (delivery to CF) Auxiliary Facility Equipment - Truss type (3.1.11) ≈ 7000 kg ea.; delivery of ACS modules to CF

MPTS - dock to bottom of Boeing Thermal SC - mass $\approx 21 \times 10^6$ kg

Boeing Thermal SC Module Attachments (4.1) - Masses 10^5 - 10^6 kg

EXISTING/POTENTIAL CONCEPTS:

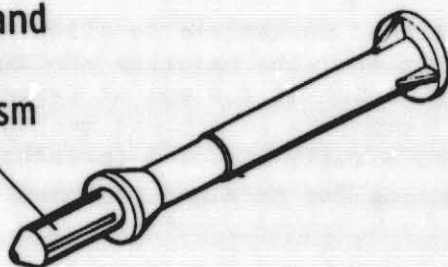
- (1) Full probe and drogue system
- (2) Universal docking adapter
- (3) General purpose attachment mechanism (not full docking)
- (4) Manual/automatic/hybrid systems

MAJOR INTERFACES: Compatible docking interface, lighting, control system (manual, automatic or hybrid)

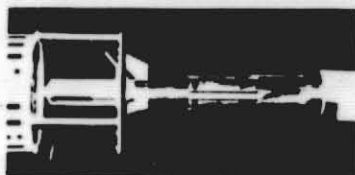
SRT REQUIRED: Transport, control, docking of very large (≥ 1 km dia.) structures of large (10^6 kg) mass

SPS IMPACTS: Class of docking devices must be identified, developed - based on SPS construction/maintenance/operations plans

**Docking and
Retrieval
Mechanism**



Insert



Latch

Data Source:

Earth Orbital Teleoperator Systems, Concepts, and Analysis, Final Report, Volume V, Docking Retrieval Mechanism--MCR-76-17, NAS8-31290, May 1976

Operational Description:

This unit consists of an extendable/probe assembly and a docking receptacle. The forward, capture/latch mechanism portion incorporates three latching prongs attached to a traveling carriage. A DC torquer motor/ball screw assembly provides the linear motion required to deploy the prongs to an angle of $\sim 45^\circ$. Subsequent travel moves the prongs rearward drawing the docking receptacle on the spacecraft into a rigid mating.

Mass Properties:

Probe Assembly: 15 Kg (35.3 lb)
Total Assembly: 48.6 Kg (107.5 lb)
Size: 20 cm (8 in.) dia., 1.8 m (6 ft) long

Requirements:

Functional -

Missions: Enables two spacecraft or payload to dock and be structurally joined on-orbit
Extension Reach: 0.9 m (3 ft) at (1 ft/sec) maximum
Docking Misalignments: Radial-- ± 5 cm (± 2 in.); lateral-- ± 0.6 cm/sec (0.02 ft/sec)
Forces: Longitudinal - 220 N (50 lb); spin torque - 2 N-m (1.5 ft-lb)
Unit Cycle Time: Capture time of ≤ 5 sec, latch time of ≤ 15 sec.

Physical -

Crew: One crew for remote control from PSS
Docking: Viewing, lighting, and compatible docking receptacle
Services: Electric power required, 28 ± 4 V DC
Interfaces: Mounting of unit, electrical, communications, etc.
Environments: Space

Comments:

An engineering prototype of the docking and retrieval mechanism was built and tested. A possible SPS construction application of this unit is as a manipulator end effector used to grip, handle, and position SPS components and construction equipment during assembly.

OCSE REQUIREMENTS DEFINITION SHEET

OCSE INVENTORY NO. 9.0

OCSE CLASS: OCSE Support Equipment

OCSE SUBCLASS: Commodity Servicer

TASK DESCRIPTION: Many of the SPS elements, pieces of construction equipment, and the identified OCSE require some sort of servicing during SPS construction. These requirements range from module replacement and fluid transfer to electrical power resupply. Some means of providing such general services is required.

APPLICATIONS TO SPS CONSTRUCTION:

Boeing Thermal - (2.1.1.5) - Leak check and service unit (supply NaK - up to 5×10^6 kg for each of 4 modules)

Commodity module replacement - small packages ($\sim 1\text{m}^3$) (CE, OCSE maintenance)

CE power resupply - all areas of SPS construction

EXISTING/POTENTIAL CONCEPTS:

- (1) Transportable service cart
- (2) Dedicated (fixed base) service station

MAJOR INTERFACES: Requires transport, handling, temporary attachment at work site (of mobile); power, lighting; EVA assistance for operation may be required.

SRT REQUIRED: Handling of large quantities of fluid; leak checks; power transfer scheme

SPS IMPACTS: - Dependent upon SPS construction/construction base philosophy

OCSE REQUIREMENTS DEFINITION SHEET

OCSE INVENTORY NO. 9.0

OCSE CLASS: OCSE Support Equipment

OCSE SUBCLASS: Storage panels

TASK DESCRIPTION: Many small (relatively) items utilized during SPS construction must be temporarily stored in close proximity to the task being performed so that they can be employed as required to complete the task. These items are EVA tools, manipulator end effectors, OCSE modular subsystems. A general purpose storage panel, to be carried as part of an OCSE item or permanently stationed at fixed sites, is required to allow easy access to necessary items.

APPLICATIONS TO SPS CONSTRUCTION: Applicable to all areas of SPS construction; probably requires several types of storage panels

EXISTING/POTENTIAL CONCEPTS:

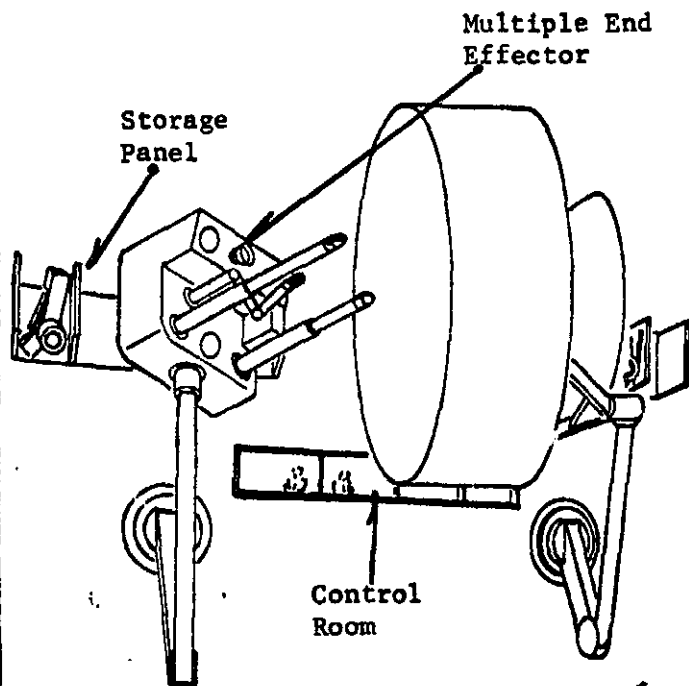
- (1) EVA tool carrier
- (2) Manipulator end-effector storage
- (3) Service cart equipment storage

MAJOR INTERFACES: Size of items to be stored; attachment to OCSE or to existing structure

SRT REQUIRED:

SPS IMPACTS: -Construction base/maintenance philosophy dictates applicability of permanently attached (to structure) vs carried-with-OCSE storage

OCSE Title: STORAGE PANELS - FACILITY BIN Category D No. 9.2



Data Source:

New

Operational Description:

Wherever there are multiple tasks to be done by one manipulator, there will probably be a storage panel of end effectors. Shown here are manipulators (used in the Maintenance and Repair Module; see OCSE summary sheet 10.3), one with a multiple end effector and one with a grappling device. Storage Panels are seen in background, on both sides of control room windows.

Mass Properties:

Requirements:

Functional - Secure/store end effectors for manipulators in MRM

Crew - None

Environment - Unpressurized

Service - None

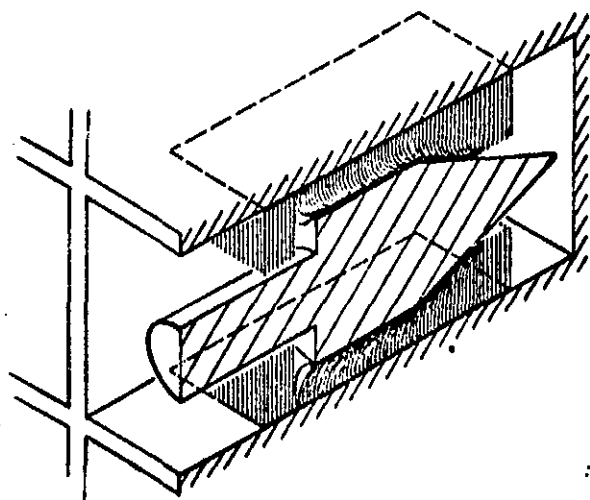
Physical - Wall-mounted units

Comments:

OCSE Title: STORAGE PANELS - BRUSH CAPTURE

Category D

No. 9.3



Data Source:

New

Operational Description:

Tools and end effectors must be easily but firmly secured in the storage panel and also easily accessible. Shown here is one method of securing tools which uses "scrub brushes" to hold the tool.

Mass Properties:

Requirements:

Functional - Secure/store tools or end effectors as required, method can be used in any storage rack

Crew - N/A

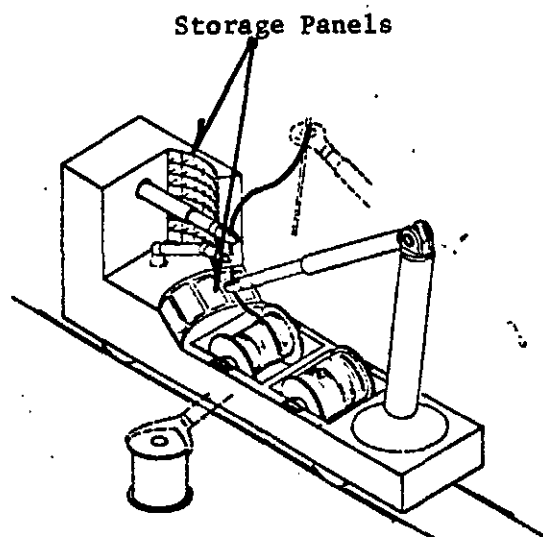
Environment - N/A

Service - N/A

Physical - any size

Comments:

OCSE Title: STORAGE PANELS (CABLE HANDLING CAR) Category D No. 9.4



Data Source:

New

Operational Description:

Another place in which storage panels must be built is in multitask mobile manipulator vehicles (if used). Shown here is the cable handling car of the Core Module shown on OCSE summary sheet 10.1. For a more detailed description of this vehicle see that summary sheet.

Mass Properties:

Dimensions: 1 x 2 x 4 meters

Requirements:

Functional - Storage panels

Crew - None, remotely controlled

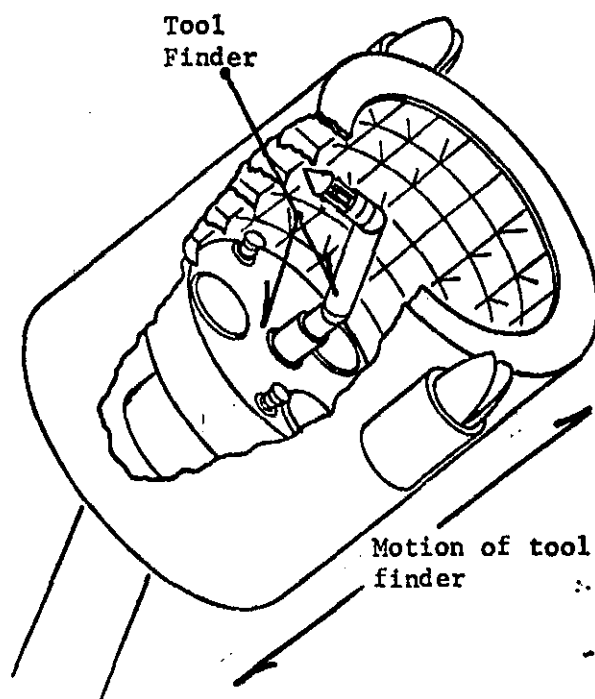
Environment - Space

Service - Resupply reels; unscheduled maintenance

Physical - Small, launched as a unit

Comments:

OCSE Title: STORAGE PANELS - CYLINDRICAL BIN Category D No. 9.5



Data Source:

New

Operational Description:

The Storage Panel is simply a tray which holds tools and end effectors until such time as they are needed by a manipulator which it serves. Shown here is one concept of a large capacity storage panel with a "line-finder" type construction.

Mass Properties:

Dimensions: Size is task dependent.

Requirements:

Functional - Secure and protect tools and end effectors until needed.

Crew - Unmanned, remote operation

Environment - Space, or unpressurized module

Service - Initial unit storage; unscheduled maintenance

Physical - Launched as a unit

Comments:

OCSE REQUIREMENTS DEFINITION SHEET

OCSE INVENTORY NO. 9.0

OCSE CLASS: OCSE Support Equipment

OCSE SUBCLASS: Modularized systems

TASK DESCRIPTION: Many of the individual pieces of OCSE require the same type of subsystems support - communications, GN&C, video capability, integral lighting, etc. These subsystems should be modularized to the maximum extent possible for interchangeability and ease of servicing.

APPLICATIONS TO SPS CONSTRUCTION: General application to all OCSE (and possibly to CE) required during SPS construction

EXISTING/POTENTIAL CONCEPTS:

Modularized systems:

- Tracking
- Communications
- GN&C
- Mounting plates
- Video
- Lighting .

} Similar to existing MMS, EOTS concepts

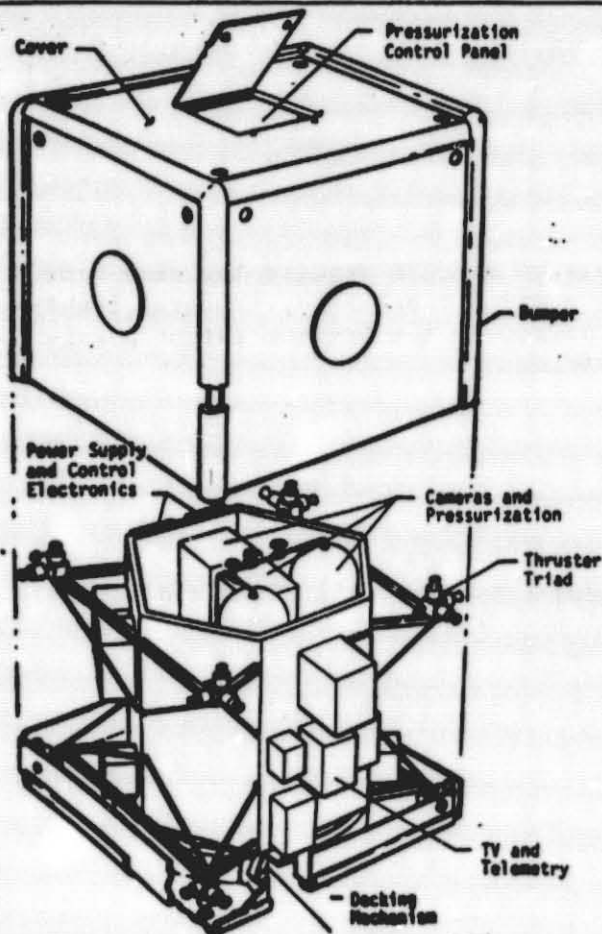
MAJOR INTERFACES: OSCE must be designed to accept modular subsystems.

SRT REQUIRED:

SPS IMPACTS: - Definition of equipment complement required to determine feasibility/cost effectiveness of modularization.

OCSE Title: Maneuvering System (MS)

Category B No. 9.6



Data Source:

Maneuvering Systems Study, IR&D No. D-25S, Report No. S76-48825-003, August 1976

Operational Description:

This unit is a small general purpose maneuvering system that can accept control inputs communicated from the Orbiter aft crew station in order to monitor or maneuver payloads in the region surrounding the Orbiter. The unit is unmanned and tailored after the design and hardware used on the Manned Maneuvering Unit.

Mass Properties:

Mass: 136 Kg (300 lbs) wet

Dimensions: 97x107x102 cm (38x42x40 in.)

Requirements:

Functional -

MS Tasks: Payload inspection, cargo transfer, contingencies, photographic surveys

Distance: Near vicinity of the Orbiter, ΔV of 650 fps

Performance: Translation velocity of 0.05 fps, limit cycle rates $< 0.1^\circ/\text{sec}$

Physical -

Crew: Minimum of one, IVA at Orbiter aft flight deck

Service: Modular subsystems, propellant resupply, electrical recharge

Interfaces: Orbiter/FSS, stowage, service, docking

Comments:

The MS may be designed and built by early 1980 for orbital support operations in conjunction with Shuttle payloads. Could also be considered a simple deploy/retrieve vehicle (DRV).

OCSE REQUIREMENTS DEFINITION SHEET

OCSE INVENTORY NO. 9.0

OCSE CLASS: OCSE Support Equipment

OCSE SUBCLASS: Subsystem Insulator

TASK DESCRIPTION: Thermal control/protection of the SPS elements, construction equipment and OCSE is a significant design factor. The optimum insulation technique or material must be developed for each of these systems. Several types will probably be developed and utilized as dictated by the particular system requirements.

APPLICATIONS TO SPS CONSTRUCTION:

General applicability to all OCSE, CE and to some SPS elements required during SPS construction.

EXISTING/POTENTIAL CONCEPTS:

- (1) Sheet insulation
- (2) Foam insulation
- (3) Paint-thermal coatings

MAJOR INTERFACES: System requirements must be identified in each case.

SRT REQUIRED: Definition of thermal control required; technique optimization

SPS IMPACTS: Study required to determine optimum thermal control method for entire SPS system; similar or analogous methods would be applied to OCSE, CE.

OCSE REQUIREMENTS DEFINITION SHEET

OCSE INVENTORY NO. 10.0

OCSE CLASS: Base Modules

OCSE SUBCLASS: CHAD Module

TASK DESCRIPTION: The CHAD module is an integral facility (maximum size - one HLLV launch - 20 meter diameter x 30 meters long) which accomplishes the initial construction steps, either for the construction base or for those portions of the actual SPS structure which are not constructed from a base facility (e.g., MPTS). The CHAD module contains all equipment (beam builders, manipulators, etc.) necessary to build/assemble the first basic section of structure.

APPLICATIONS TO SPS CONSTRUCTION: Used for beginning construction of the construction base for any SPS; used for building MPTS.

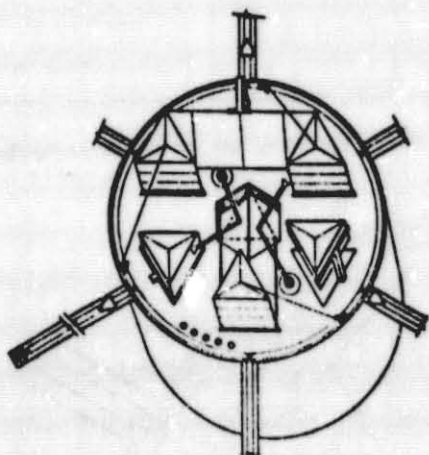
EXISTING/POTENTIAL CONCEPTS:

- (1) Cube builder
- (2) Wedge builder
- (3) MPTS assembler

MAJOR INTERFACES: Space station modules; other HLLV modules. CHAD module may contain additional CE or OCSE.

SRT REQUIRED: Tradeoff of applicability to SPS construction bases, MPTS; design requirements must be defined.

SPS IMPACTS: Design/applicability based on philosophy for initial construction.



Data Source:

New

Operational Description:

The STAD is a general purpose CHAD module capable of constructing a number of SPS structural elements in sequence. The module contains beam fabricators, manipulators and cable reels, support arms which drive the module back along the completed beams and radial extension arms used to assist some construction steps.

Mass Properties:

Dimensions: 20 meter diameter x 30 meters long

Requirements:

Functional -

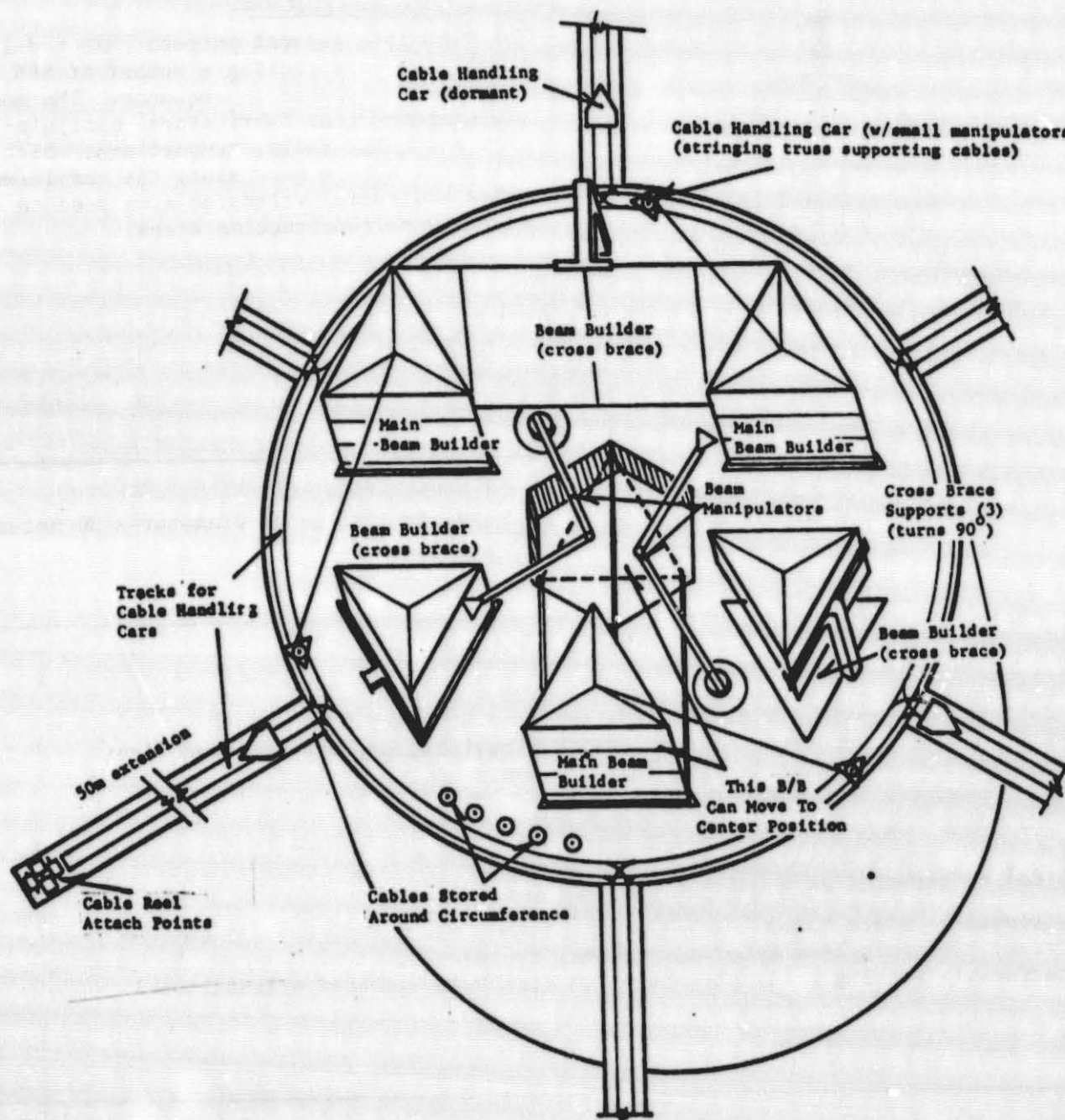
Operation: Automatic, twice per SPS; assisted by other OCSE and CE
 Task (typical): Construct MPTS extension structure, support arms and first concentric ring radial members
 Crew: Unmanned; remote monitoring only

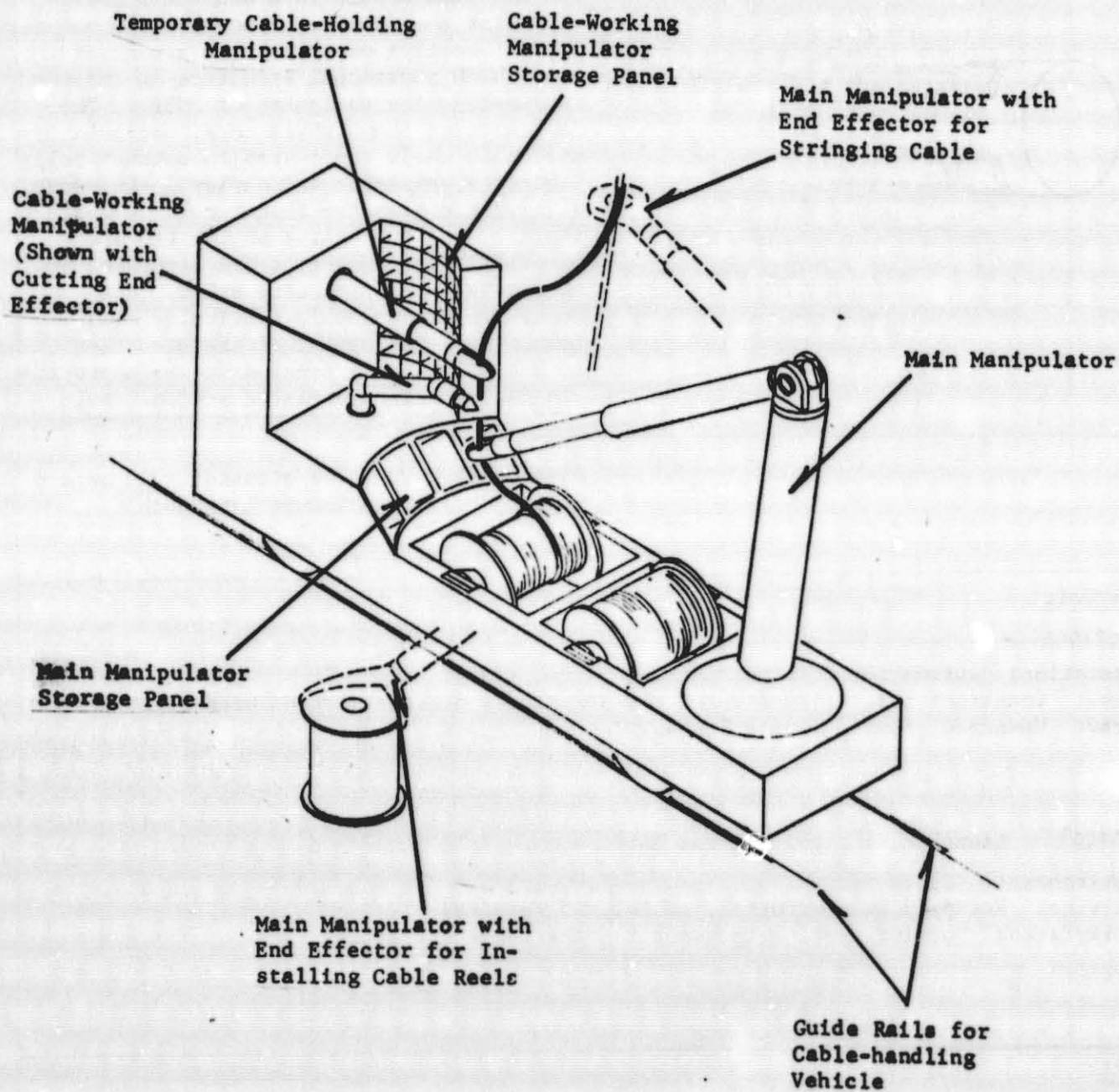
Physical - Launched as a unit in one HLLV

Environment: Space vacuum
 Service: Resupply beam material, cables, as required
 Interfaces: Docking port, attachment to structure (several orientations)

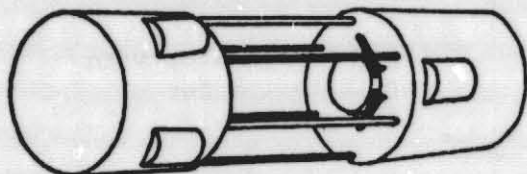
Comments:

A fully independent, general purpose CHAD module may be very complex. The concept shown can accomplish some of the major MPTS construction tasks, but requires support from other OCSE or construction equipment before, during and after its normal operation.





Cable-Handling Vehicle



Data Source:

New

Operational Description:

The LAD CHAD module is a dedicated facility which can fabricate and assemble an initial section of structure (around or onto which additional structure is attached by construction equipment or OCSE). The LAD contains beam fabricators, manipulators and cable reels configured to automatically fabricate, assemble and deploy a structure of specific geometry (e.g., cube or wedge shape). The two halves of the LAD are identical, and construct the structure as they move apart from each other. Six beams are continuously fabricated simultaneously. Deployment of the structure is accomplished by tensioning the appropriate cables. The completed section could

Mass Properties:

Dimensions: 20 meter diameter x 30 meters long (2 halves 15 meters long each)

Requirements:

Functional -

Operation: Automatic, once per SPS

Task: Construct initial section of SPS structure, or construction base structure

Crew: Unmanned, remote monitoring only

Physical - Launched as a unit in one HLLV

Environment: Space vacuum

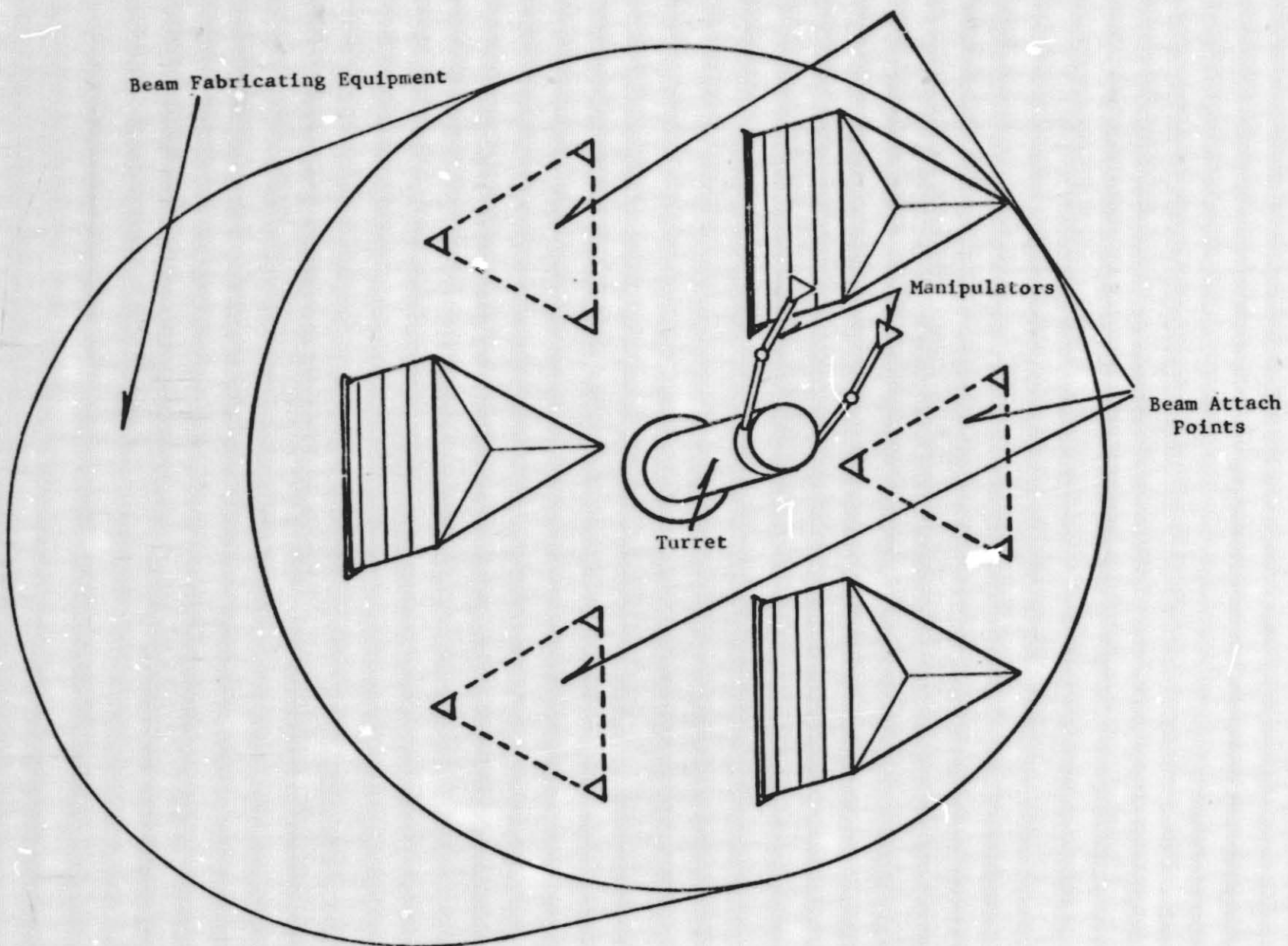
Service: Resupply beam material, cables, if required

Interfaces: Docking port, attachment to other base facilities

Comments:

The LAD concept shown can be adapted to any specific structure geometry and size, but each module can do only one task. Its principal advantages are its relative simplicity and the degree of automation possible during the major assembly phases.

be part of a larger construction base, or part of the SPS structure itself.



LAD Module for Cube (1 of 2)

OCSE REQUIREMENTS DEFINITION SHEET

OCSE INVENTORY NO. 10.0

OCSE CLASS: Base Modules

OCSE SUBCLASS: Maintenance and Repair Module

TASK DESCRIPTION: Provide a centralized facility for the repair and maintenance of all OCSE. Operations performed with this facility would include inspection battery recharging, subsystems module replacement, component repair (on "time available" basis), scheduled/unscheduled servicing of vehicles. The facility would have an open hanger (unpressurized) section, docking ports, and a pressurized work (bench) area. Operations would be monitored/controlled from a pressurized control/display module within the facility.

APPLICATIONS TO SPS CONSTRUCTION: Applicable as a general facility to all SPS construction; a space station/construction base logistics facility might include this type of module for maintenance/repair of CE, OCSE, orbit transfer vehicles, etc.

EXISTING/POTENTIAL CONCEPTS:

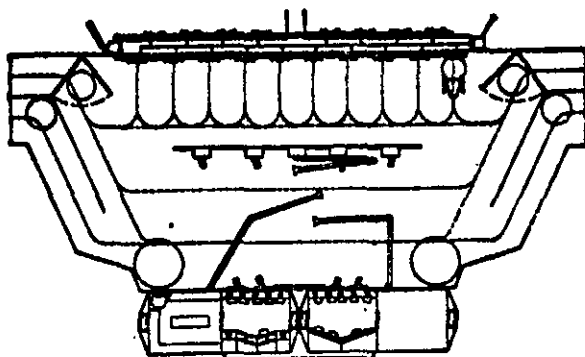
- (1) Space station modules
- (2) Construction base facilities
- (3) Separate OCSE module

MAJOR INTERFACES: Docking ports; other construction base facilities; handles surface transport vehicles, free flyers, ECWSs

SRT/SPECIAL TRADEOFFS REQUIRED: Refueling in space (high pressure gas, cryogenics); tradeoff of separate OCSE module vs. incorporation into larger SPS facility.

SPS IMPACTS: Probably is part of the larger space station/construction base complex; could also be combined with the commodities storage module.

OCSE Title: MAINTENANCE AND REPAIR MODULE (MRM) Category D No. 10.3



Data Source:

New

Operational Description: (See also Sheet 2)

The MRM is a single, centralized facility wherein all maintenance and repair of OCSE would be performed. It would service vehicles/equipment on a day-to-day basis, accomplish scheduled maintenance and replace failed subsystems as required for repair. Operations would be completed automatically and remotely, with overall control maintained from a pressurized control room configured for direct and indirect monitoring. Work rooms would also be pressurized to allow shirt-sleeve operations.

Mass Properties:

Dimensions (typical): 250 meters x 100 meters x 50 meters

Requirements:

Functional -

Operation: Assembled in orbit, operates during total construction phase.

Task: Maintenance, repair, servicing of OCSE, some CE and OTVs.

Crew: 2 to 10, all IVA (in control room) except for contingencies (EVA in bays).

Physical -

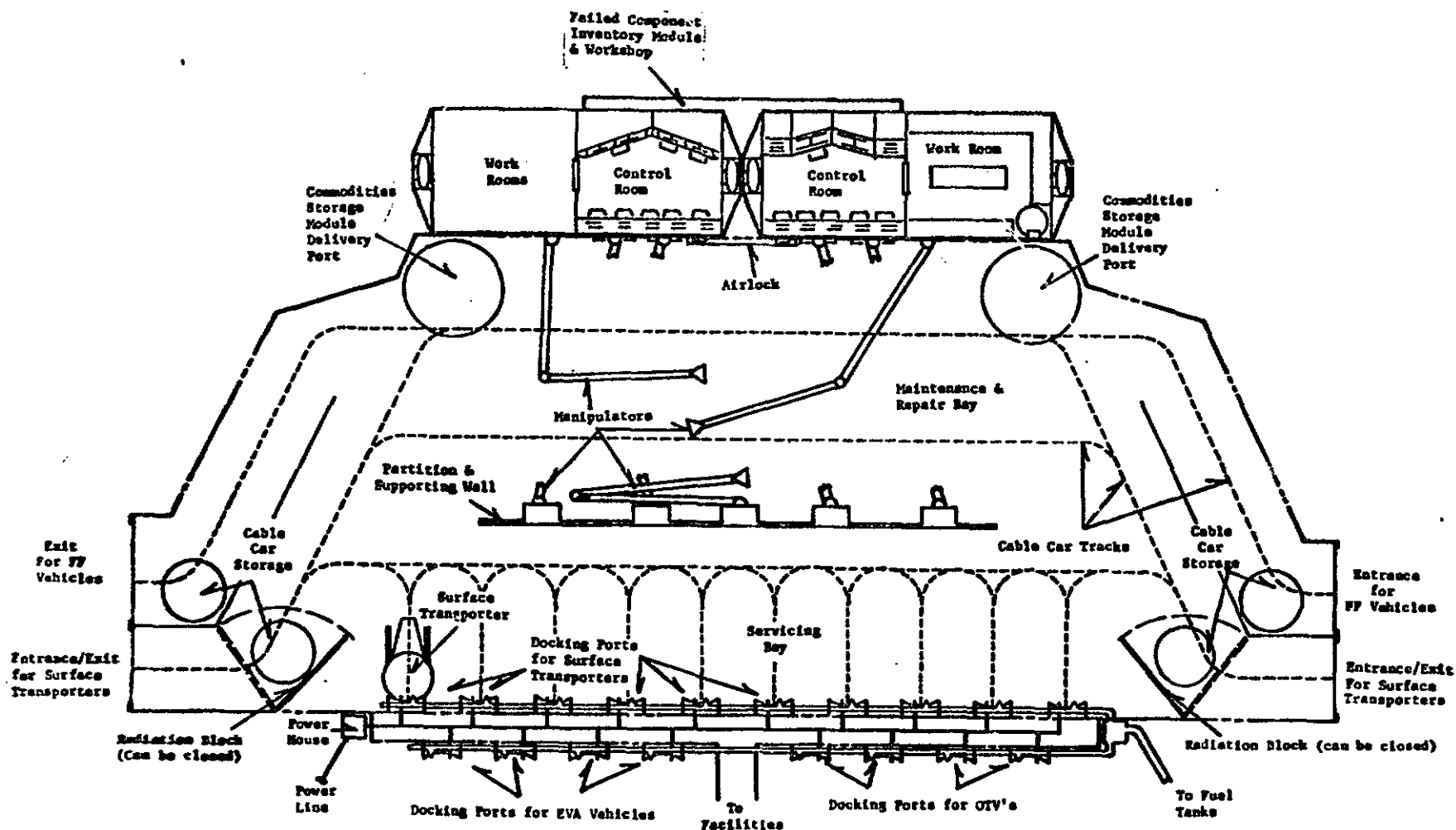
Environment: Vacuum, enclosed (but not sealed) work bays; control room pressurized.

Service: Commodities resupply, power.

Interfaces: Attached to structure, to other construction facilities; external docking for vehicle servicing, MRM resupply.

Comments:

MRM could be incorporated (functionally or physically) into a larger facility for the entire SPS. Additional, separate servicing locations may be required as remote stations (of unique design).



OCSE REQUIREMENTS DEFINITION SHEET

OCSE INVENTORY NO. 10.0

OCSE CLASS: Base Module

OCSE SUBCLASS: Assembly Jigs

TASK DESCRIPTION: Provide a work base, structure or platform around or within which construction tasks are accomplished. Jig configuration is dependent upon the shape of structure to be built (i.e., may be inherently task unique); linear dimensions can be up to several kilometers. Jig itself may require assembly on-orbit.

APPLICATIONS TO SPS CONSTRUCTION:

Boeing Thermal (2.1.1.1) - Cavity absorber shell jig - hexagon of 8 meter square beams x 125 meters long each

MPTS (X.2.1.1, X.2.1.2) - extension structure jig - moving over length of extension structure, 750 to 1000 meters; cross section ~50m x 50m

Truss type - (1.1) - Construction base facility - 5200m x 600m x 1300 meters

EXISTING/POTENTIAL CONCEPTS:

- 1) Grumman OCDA work platform
- 2) Truss type construction facility (Boeing)

MAJOR INTERFACES: Material supply vehicles (free-flying or surface attached); docking ports; manipulative systems (fixed base or mobile)

SRT REQUIRED: Applicability of jigs to SPS construction (below construction base level) needs to be demonstrated.

SPS IMPACTS: Jigs may be efficient construction method even for relatively small structural elements, if the same jig can be utilized for construction of many SPSs.

OCSE REQUIREMENTS DEFINITION SHEET

OCSE INVENTORY NO. 10.0

OCSE CLASS: Base Modules

OCSE SUBCLASS: EVA Module

TASK DESCRIPTION: Provide an enclosure/vehicle which provides standby EVA crews a low pressure (~ 4.0 psia) oxygen environment within which they can prepare for EVA tasks. The module would house a crew of from 2 to 10 people for up to two weeks, and therefore must contain personal hygiene facilities, sleeping quarters and eating provisions.

APPLICATIONS TO SPS CONSTRUCTION: Generally applicable to all SPS construction, although EVA crew sizes and work tour durations have not been defined. Some EVA tasks associated with construction have been identified; in addition, EVA maintenance and repair, and EVA rescue, are anticipated tasks during and after SPS construction.

EXISTING/POTENTIAL CONCEPTS:

- 1) Use Skylab MDA/AM configuration shell

MAJOR INTERFACES: Base habitat facility; life support systems; EVA vehicles/docking ports; airlocks

SRT REQUIRED: Shuttle-era suit technology and pre-breathing requirements will affect design of module. Optimum working pressure in facility must be defined (in relation to suit pressures and ease of facility design).

SPS IMPACTS: Anticipated EVA work schedules, crew size and activities definition will determine requirements for EVA module.

OCSE REQUIREMENTS DEFINITION SHEET

OCSE INVENTORY NO. 10.0

OCSE CLASS: Base Modules

OCSE SUBCLASS: Commodities Storage Module

TASK DESCRIPTION: Provide a centralized facility to house the components, supplies, and commodities required by OCSE. Materials contained within the module would include fuel, fuel tanks, batteries, spare parts, tool kits (for EVA use), replacement end effectors, subsystems (communications, GN&C, etc.) modules, etc. The facility would have an open hanger (unpressurized) section, docking ports and a small pressurized work area. This module could also serve as a storage area for idle OCSE vehicles or equipment.

APPLICATIONS TO SPS CONSTRUCTION: Applicable as a general facility to all SPS construction; a space station/construction base logistics facility might include commodities storage for OCSE, CE, orbit transfer vehicles, etc.; i.e., base facilities should include all commodities storage.

EXISTING/POTENTIAL CONCEPTS:

- (1) Space station modules
- (2) Construction base facilities
- (3) Separate OCSE module

MAJOR INTERFACES: OCSE vehicles/commodities - logistics and supply control; other construction base facilities; docking ports

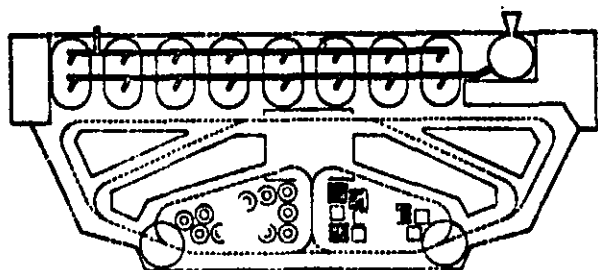
SRT/SPECIAL TRADEOFFS REQUIRED: Tradeoff of separate OCSE module vs incorporation into larger SPS facilities.

SPS IMPACTS: Probably is part of the larger space station/construction base complex; could also be combined with the maintenance and repair module.

OCSE Title: COMMODITIES STORAGE MODULE (CSM)

Category D

No. 10.4



Data Source:

New

Operational Description:

The CSM is a single, centralized facility which houses the supplies, commodities and replacement parts required by OCSE. Its primary functional interfaces would be to accept supplies from delivery vehicles and deliver those supplies as required to the MRM. Item retrieval from storage would be remotely controlled from a pressurized work area.

Mass Properties:

Dimensions (typical): 200 meters x 100 meters x 50 meters

Requirements:

Functional -

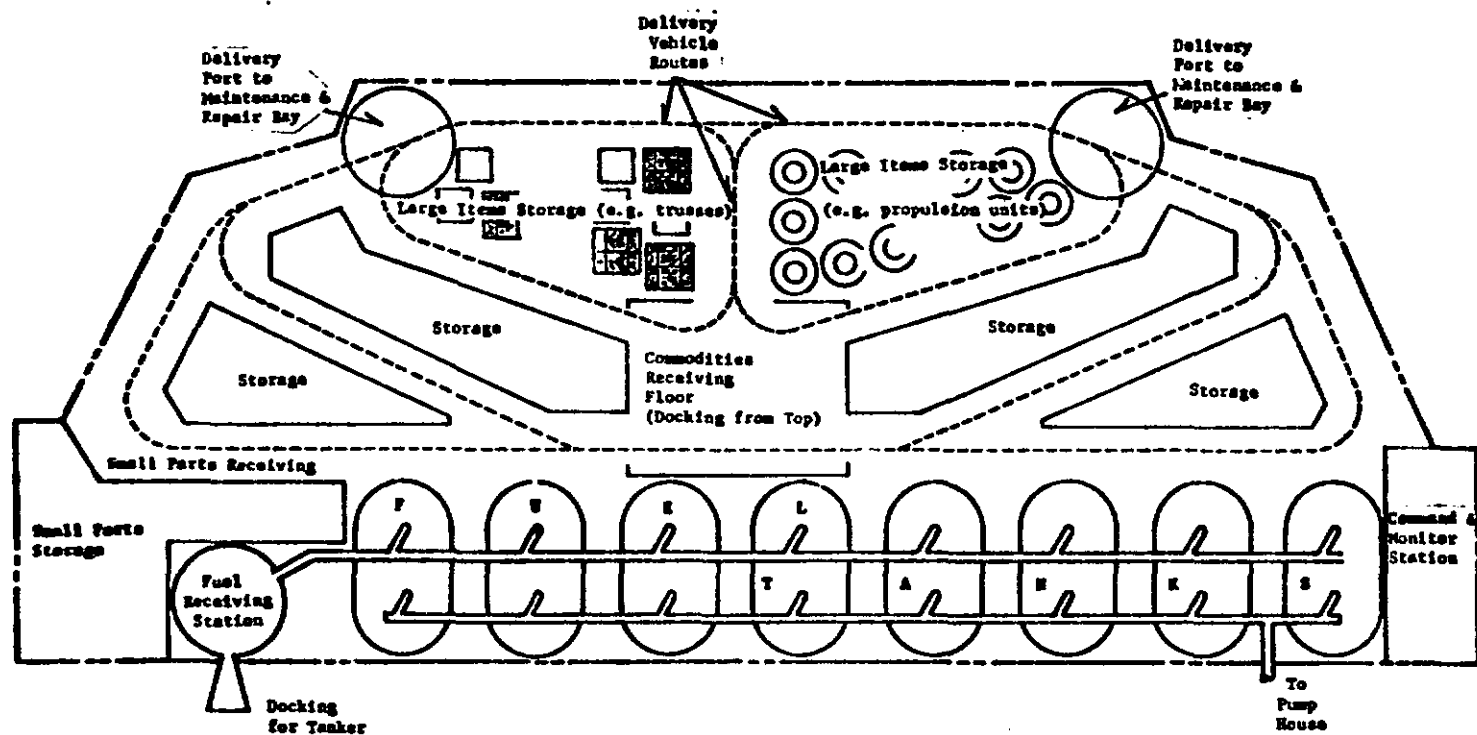
Operation: Assembled in orbit; operates during total construction phase
Task: Store supplies for all OCSE; retrieve items as required and deliver to MRM; accept resupply at docking port
Crew: 1 to 3 men, all IVA (in control room)

Physical -

Environment: Vacuum, enclosed (but not sealed) storage bays; control room pressurized
Service: Resupply as required; power
Interfaces: Docking port for resupply vehicle; delivery ports to MRM

Comments:

Could be part of a larger facility for entire SPS; could also be attached to maintenance and repair module for better logistical control.



OCSE REQUIREMENTS DEFINITION SHEET

OCSE INVENTORY NO. 11.0

OCSE CLASS: Integrated Systems, Special Class

OCSE SUBCLASS: Manned Cherry Picker

TASK DESCRIPTION: Provide a platform from which multiple tasks can be performed directly by an operator. The platform should be mobile (attached to boom, free flying, or manipulator attached) and can contain its own manipulators. Depending upon the particular task to be performed, the optimum platform configuration could be a pressurized enclosure for shirtsleeve operations, or an open bucket with a pressure-suited operator. In the most complex option, the cherry picker would be an integrated system containing its own power, communications, manipulators, monitoring and transport subsystems.

APPLICATIONS TO SPS CONSTRUCTION:

Thermal SPS (2.1.1.3) - Install, checkout, repair turbogenerator sets.
MPTS - (3.2.1.6) - Install switch gears
General assistance during assembly and operational maintenance of SPS.

EXISTING/POTENTIAL CONCEPTS:

- (1) Free flying, with manipulators
- (2) Attached to long boom, with manipulators
- (3) Structure attached

MAJOR INTERFACES: Life support systems, transport interface (boom, structure, or docking mechanism).

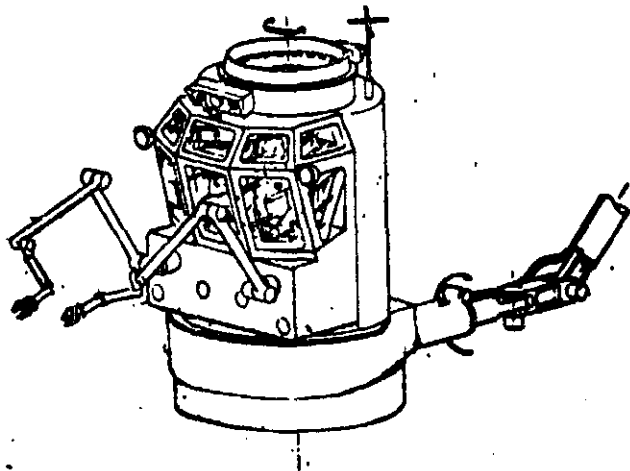
SRT REQUIRED: Radiation hazard in GEO; multiple manipulator control.

SPS IMPACTS: Effective utilization of capabilities of man requires optimum cherry picker design.

OCSE Title: MANNED CHERRY PICKER

Category D

No. 11.1



Data Source:

New

Operational Description:

A manned cherry picker is a vehicle which, through the use of articulated booms attached to structure, positions its bucket (which carries the operator and his equipment) as directed by the operator's controls. It can be used as a platform for many tasks.

Mass Properties:

Requirements:

Functional -

Crew: Minimum 1 Operational, 2 Rescue

Environment: Structure attached

Service: Recharging of life support and power daily; scheduled servicing

Launch Vehicle: Launched in small sections

Physical -

Comments:

"Manned Cherry Picker" refers to a number of different possible configurations. The platform can be open or closed, pressurized or unpressurized. The platform can double as a free flyer. The booms can be attached to structure or to a vehicle. Many more possibilities exist.